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THESIS

A VISUAL LANGUAGE FOR SITUATIONAL AWARENESS

by

David L. De Marco

December 2016

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What is the best way for the various responder silos to communicate situational awareness information across complex homeland security incidents? With the advent of wireless data networks, homeland security responders have the opportunity to instantly communicate vast volumes of information across myriad local, state, and federal resources. Finding a common, interoperable language for a network-centric response environment is essential to avoid duplicating the patchwork of communication techniques in place today. A comparative analysis between Department of Defense and Department of Homeland Security finds the agencies have very similar situational awareness needs. The Department of Defense is more advanced in its development of networked situational awareness communication. The humble map lies at the heart of situational awareness tools and requires a common visual language to be interoperable. This thesis recommends a common national symbols set that visually communicates situational awareness across a network. Applying semiotic principles to symbols creates a visual metalanguage that answers not only "What?" and "Where?" questions, but also provides essential operational context by incorporating the attributes of incident resources into the symbols themselves.

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A VISUAL LANGUAGE FOR SITUATIONAL AWARENESS

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ABSTRACT

What is the best way for the various responder silos to communicate situational awareness information across complex homeland security incidents? With the advent of wireless data networks, homeland security responders have the opportunity to instantly communicate vast volumes of information across myriad local, state, and federal resources. Finding a common, interoperable language for a network-centric response environment is essential to avoid duplicating the patchwork of communication techniques in place today. A comparative analysis between Department of Defense and Department of Homeland Security finds the agencies have very similar situational awareness needs. The Department of Defense is more advanced in its development of networked situational awareness communication. The humble map lies at the heart of situational awareness tools and requires a common visual language to be interoperable. This thesis recommends a common national symbols set that visually communicates situational awareness across a network. Applying semiotic principles to symbols creates a visual metalanguage that answers not only “What?” and “Where?” questions, but also provides essential operational context by incorporating the attributes of incident resources into the symbols themselves.

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LIST OF ACRONYMS AND ABBREVIATIONS

4GLTE	4th Generation Long Term Evolution
ACCOLC	Access Overload Control
ANSI	American National Standards Institute
BFT-2	Blue Force Tracker
CAD	computer aided dispatch
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DOD	Department of Defense
FBCB2	Force XXI Battle Control Brigade and Below
FEMA	Federal Emergency Management Agency
FirstNet	First Responder Network Authority
GAO	Government Accountability Office
GIS	geographic information system
GPS	global positioning system
IMS	Incident Management System
INCITS	International Committee for Information Technology Standards
MANET	mobile ad-hoc network
mHz	megahertz
NICS	Next Generation Incident Command
NIMS	National Incident Management System
NPSBN	National Public Safety Broadband Network
NRF	National Response Framework
PNNL	Pacific Northwest National Laboratories
PPD	Presidential Policy Directive
PSCR	Public Safety Communications Research Council
SCOUT	Situation Awareness and Collaboration Tool
SME	subject matter experts
TCP/IP	transfer control protocol/internet protocol
VHF	very high frequency
WIN-T	Warfighter Information Network-Tactical

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EXECUTIVE SUMMARY

Can responders from various disciplines communicate situational awareness more effectively during homeland security incidents?

Homeland security incidents vary widely in type and scale, from minor local events contained within one jurisdiction to major events that might span local, regional, and state boundaries. Responder's decisions must be supported by the best possible information to reduce losses and mitigate incidents. Case studies have found confusion and miscommunication contribute to the loss of life, property, and the squandering of precious resources despite advances in incident command training and improved wireless communication tools. Responder reliance on voice communications for information exchange has repeatedly failed to provide the necessary situational awareness required to support decision making.

Increasingly present in the response environment is the wireless data network. This development follows the example of the Department of Defense (DOD), which has committed itself to the use of a network for improving its warfighting effectiveness. The DOD has reported to Congress that a network improves information sharing, which enhances the quality of available information and improves self-synchronization of forces. These facts dramatically increase mission effectiveness. The DOD has identified "network-centric warfare" as their top modernization priority and the most effective means of providing effective decision support to its warfighters.

The situational awareness needs of warfighters and homeland security responders are strikingly similar. A comparative analysis was performed to see if the DOD situational awareness doctrine could be applied in a useful way to answer the thesis question. Warfighters and responders face different enemies but similar circumstances, including danger, uncertainty, fluidity, disorder, and complexity. These factors comingle to create Carl von Clausewitz's "fog of war" on the battlefield and in the homeland, wreaking havoc in both environments. The DOD is utilizing a network to clear this fog with field-deployable network infrastructure and a variety of software tools to provide situational awareness within the networked battlespace. Blue-force tracker, Link 16, Force XXI Battle Brigade and Below are all situational awareness software tools intended to share information among warfighters. These tools serve as an example to homeland security responders, and at the heart of each of these complex tools, lies the humble map.

The tenets of network-centric warfare apply to homeland security response, giving rise to the need of doctrine for a network-centric response environment. There is a national effort to create a common homeland security wireless network known as FirstNet. FirstNet creates the infrastructure necessary to support network-centric response, but what software will run on that infrastructure? What will the common language of situational awareness be? A variety of tools are in development nationally but they are each unique, and expose the nation to another layer of interoperability issues caused by patchwork regional solutions. Following in the footsteps of the DOD, a map lies at the heart of domestic situational awareness tools in development. National policy must guide the development of a common language communicated within a networked, mapped environment to ensure all users are able to share situational awareness and collaborate on decisions.

Mapping is a visual medium whether on paper or in a digital environment. Digital maps allow for the development of a geographic information system, which symbolizes tabular data for easy visual communication and correlation to a specific geography. The symbols overlaid on a geographic information system play an essential role in information exchange. One previous national effort has been undertaken to standardize those symbols for improved interoperability. ANSI INCITS 415—Homeland Security Mapping Standard attempts to build a common language for maps in the homeland security environment but has been poorly accepted and largely ignored by the professionals who use homeland security mapping products. This thesis argues ANSI failed because their standard does not utilize simple semiotic principles nor provide useful context to the user.

A national symbol set designed for use in a full-color, networked response environment is sorely needed. By applying simple semiotic principles to symbols design, they can become an easy-to-interpret visual metalanguage. Symbols differentiated by color, shape, size, texture, and vector might sound simplistic but are currently not defined nationally. By using these principles on information drawn from the attribute table of the resource itself it is possible to create compounded symbols, which add the needed context demanded by homeland security decision makers.

This thesis makes six recommendations to achieve a national visual language to capture the known benefits of a network in the homeland security response environment:

- Identify the tenets of network-centric response as essential to the Homeland Security enterprise.
- Identify a geographic information system as the preferred platform upon which networked visual communication of situational awareness will occur.
- Define a common set of cartographic pragmatics specific to homeland security mapping applications.
- Symbolize the Federal Emergency Management Agency's (FEMA) resource guidebook to create an initial national homeland security point symbols set.
- Use subject matter experts to create attribute tables for all typed homeland security resources.
- Define modifiers for the national symbols set drawn from the attribute tables of resources to create useful context within each symbol.

Application of these recommendations will improve national interoperability and deliver the known benefits of a network to support homeland security decision makers. The resulting improved situational awareness will improve the efficiency of operations and reduce losses of life and property.

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I. THE EVOLUTION OF NETWORK-CENTRIC SITUATIONAL AWARENESS

A. THESIS QUESTION

This thesis answers the question: Can responders from various disciplines communicate situational awareness more effectively during homeland security incidents?

With the arrival of mobile wireless broadband data networks, there is an opportunity to dramatically improve how situational awareness will be shared among the various responder communities that manage incidents of all types and scales. The need for a common operating picture among all assets operating at an incident is essential. There are efforts occurring on multiple fronts to develop technologies to assist responders with this need, but without clear direction set in policy, it is likely that regional solutions will develop that are not interoperable on a national scale. This thesis will research the various concepts of situational awareness sharing currently in development. It will also identify shortcomings in national policy and recommend a national strategy for best practices. Developing a common language for responder situational awareness sharing is paramount and may be better accomplished using principles defined in the science of the human perception of symbols, known as semiotics.

B. INTRODUCTION

Emergency responders manage complex, fluid events fraught with uncertainty and danger each and every day. Those responders go to great lengths to communicate with one another the details of events as they unfold in an effort to share what has happened and what is happening to anticipate what might happen as the event unfolds into the future. Their purpose is to protect responder safety while attempting to protect the lives, property, and well-being of the citizens they serve. These communicated bits of data are used to build a common operating picture and situational awareness among responders. For generations, those data exchanges have occurred by voice or written word through a progression of technologies.

It is, unfortunately, common for those data exchanges to fall short of a depiction of the complete picture, and lives are lost, property is destroyed, and scarce resources are squandered as a result. The stakes could not possibly be higher, and are best depicted by the words of responders themselves:

> I listened to the radio as officers tried to determine where in the parking lot off Lamar street the shooter or shooters might be—frantically searching, trying to find out where he, she, they could be… I got close and saw a crowd of officers and stopped to ask them where the field command post for the demonstration was. They weren't sure although it turned out it was about a half a block away. I got my bearings and found it in the confusion.[1]
>
> —Major Max Geron, Dallas Police Department, reflecting on his response to the assassination of officers on July 7, 2016

This single unit of confusion, compounded and amplified across an incident scene where dozens to hundreds of responders are operating with similar questions, then multiplied by the number of agencies involved is the issue this paper attempts to address. Despite advances in incident command training and improved tools for wireless communications, responder reliance on voice communications for situational awareness data has failed to address the confusion of Major Geron during a critical incident. His reflection shows that he, as well as other officers at the scene, were operating in a state of confusion, not just about the location of the perpetrator(s), but of basic, preplanned, knowable information about Dallas police resources, locations, and asset statuses. This confusion repeats itself over and over again nationally, at incidents as small as a residential fire to multi-state natural disasters. The result of this confusion is always the same: lives lost, property destroyed, and opportunities for efficiencies squandered. There is only one other place where Americans face comparable complexity, danger, and uncertainty: the battlefield. Perhaps we can look there for answers to these persistent problems.

Information surrounds homeland security incidents of all kinds, from a traffic accident to a complex multi-state hurricane and everything in between; effective

[1] Max Geron, "Reflections by a Dallas Police Officer," Center for Homeland Defense and Security, July 11, 2016, https://www.chds.us/c/item/3918.

planning, response, mitigation, and recovery decisions are dependent on sharing the right information with the right people at the right time. Victims, bystanders, responders, and emergency managers are dependent on this shared information for the creation of a shared understanding about what has happened, what is currently happening, and what is forecast to occur in the future. This shared understanding is known as situational awareness, or a common operating picture; for the purposes of this research, the two terms shall be used interchangeably.

Homeland security incidents requiring an incident management system often involve a response from multiple agencies, multiple disciplines, and potentially local, state, and federal assets. Large-scale events can occur across wide geographical areas or even in multiple separate geographic areas. Maintaining situational awareness and a common operating picture throughout the Incident Management System (IMS), from the command post to the operator in the field, is essential for safe, effective and efficient operations.

Often situational awareness information within one discipline is not shared with other disciplines involved in the same incident. There are many cases where the loss of a common operating picture across disciplines has resulted in deaths, injuries, property damage, or inefficient use of resources. Research is directed at determining the effectiveness of existing situational awareness sharing methodologies and identifying opportunities for improved response effectiveness and efficiency. The sharing of situational awareness data is done through a variety of communications methods, and for the purposes of this thesis, communications is defined as:

> Information transfer and involves the technology associated with the representation, transfer, interpretation, and processing of data among persons, places, and machines. It includes transmission, emission, or reception of signs, signals, writings, images, and sounds or intelligence of any nature by wire, radio, optical, or other electromagnetic systems.[2]

On the simplest of levels, communications must have a common language to be successful. While this may seem rudimentary, the relevant issue is not the intermixing of

[2] U.S. Department of Homeland Security, *National Response Plan* (Washington, DC: U.S. Department of Homeland Security, 2004), 113.

foreign languages within a response framework, but the intermixing of the various prevention, response, mitigation and recovery terms, each with their own industry-specific vernaculars. Finding a common language for the various responder disciplines is essential to the communication of situational awareness. Communications between international responders who speak different languages are beyond the scope of this thesis.

Large-scale events requiring designated, professional incident management teams will draw resources of all kinds to the event. Each of these resources is potentially drawn from different jurisdictions, different professional disciplines, and potentially, from around the country or around the world. These myriad responder silos develop independent of one another, and while there is some effort to standardize much of the intra-disciplinary jargon through national standards and federal response guidebooks, the effort has to date been largely unsuccessful.[3] Responders continue to use silo-specific terminology and phrasing, decreasing situational awareness across an incident when communicating outside their silo.

This thesis will investigate the cognitive barriers to verbal communication of data between responders, and propose a common and easily understood visual language as a solution. I am proposing the development of simple, contextually relevant symbols for each responder silo. When designed to convey contextually rich information in an easily interpretable way, a visual language maximizes the benefits of communicating via a broadband network.

A basic symbols set for each discipline, when coupled with tools like next-generation incident command and other geographic information system (GIS)-based software in a network-centric response environment will likely be far more effective at communicating developing information across a theater-wide network of responders than any tool in use today. This thesis will include determining the appropriate policies needed to govern the systematic development of network-centric situational awareness

[3] Heather K. Meeds, *Communication Challenges during Incidents of National Significance: A Lesson from Hurricane Katrina* (Carlisle Barracks, PA: U.S. Army War College, 2006), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA448607.

communication tools. Recommendations will adhere to basic semiotic principles and guidelines with examples from various sources. Within each responder discipline, there is likely a national standard-setting association that should be tasked with determining what contextual data within their silo are most relevant to situational awareness. This thesis will identify a method for developing contextually relevant visual communications in a network-centric response environment, overseen by subject matter experts within each response discipline.

The Department of Defense (DOD) has coined the term "network-centric warfare"[4] to describe the electronically interconnected command and control features of the modern battlefield. The wireless network was identified as a tool that could increase "synergy for command and control," resulting in more effective decisions by fighting forces.[5] Since the early 21st century America's armed forces have introduced networked information systems throughout the various branches of service creating network-centric fighting forces on land, at sea, and in the air. Technological limitations have kept this network from reaching the single warfighter resolution, but research on networking each soldier is underway. U.S. Army General Stanley McChrystal was an early believer in the power of networked information on the battlefield, stating:

> It became clear to me and to many others that to defeat a networked enemy we had to become networked ourselves. We had to figure out a way to maintain our traditional capabilities of professionalism, technology, and when needed, overwhelming force, while achieving levels of knowledge, speed, precision, and unity of effort that only a network could provide.[6]

The fog of war faced by American warfighters is very similar to the confusion of homeland security responders and the DOD may set numerous examples useful to civilian responders. General McChrystal's goals of knowledge, speed, precision, and

[4] Clay Wilson, *Network Centric Operations: Background and Oversight Issues for Congress* (CRS Report No. RL32411) (Washington, DC: Congressional Research Service, 2007), http://www.fas.org/sgp/crs/natsec/RL32411.pdf.

[5] Ibid.

[6] Sandra Erwin, "U.S. Troops Loaded with Technology, But Can't Harness the Power of the Network–Blog," National Defense Magazine, February 23, 2011, http://www.nationaldefensemagazine.org/blog/Lists/Posts/Post.aspx?ID=327.

unity of effort closely align to the needs of the Department of Homeland Security (DHS) and those of first responders everywhere. The DOD has clarified its view of the value of network-centric warfare to warfighters in a report to Congress:

- A robustly networked force improves information sharing.
- Information sharing and collaboration enhance the quality of information and shared situational awareness.
- Shared situational awareness enables self-synchronization.
- These, in turn, dramatically increase mission effectiveness.[7]

A better description of the information needs of responders at homeland security incidents could not be drafted. To that end, the DHS should consider the value of defining a common language within network-centric response.

This thesis presupposes that while the term "network-centric response" has not yet found its way to mainstream DHS doctrine, the development of networked response is well underway. A wide variety of networked response applications are already in use or development across the nation. Congress has agreed to its value by allocating electromagnetic spectrum for the development of a dedicated wireless broadband network specifically for homeland security use known as First Responder Network Authority (FirstNet).[8] FirstNet is intended to be used for interoperable responder communications and the delivery of rich media, without the fragility and patchwork nature of the commercial broadband networks or existing land-based mobile radio systems.[9] What has not been made clear is the manner in which this rich volume of information will be communicated, nor how responders will learn to communicate with a common language that is easily understood between the various disciplines at the local, state, and national level. This thesis will argue that semiotics will help define a common visual communication language more robust than verbal exchange or written words. Such a

[7] U.S. Department of Defense, "Network Centric Warfare Department of Defense Report to Congress," July 27, 2001, http://www.dodccrp.org/files/ncw_report/report/ncw_cover.html.

[8] First Responder Network Authority, *Public Safety Advisory Committee Fact Sheet* (Reston, VA: First Responder Network Authority, 2015), http://www.firstnet.gov/sites/default/files/PSAC%20Fact%20Sheet_120115_0.pdf.

[9] Ibid.

visual language is effective in a variety of mediums but is ideal when communicated across a digital network.

Tools and applications to this end are present in DOD and civilian programs. While research is underway to bring a wireless information network to the individual soldier, firefighter, or police officer, there is currently no effective solution at such a fine resolution. This thesis will be limited to methods for sharing situational awareness across an entire theater of operations between mounted unit resources. Recommendations will not address the networking of individual responders. Additionally, recommendations will be general enough to be applicable to the various response silos while leaving room for experts from each industry to decide what information items are considered to be contextually relevant. This thesis will attempt to describe a semiotic framework for visual communication, from within which each discipline will be responsible for refining its own terms. The study of military capabilities is also limited to the public domain; no classified materials were available for the development of this thesis.

Upcoming chapters include a comprehensive literature review that will describe the body of policy surrounding situational awareness in homeland security incidents, the current state of the art in network-centric response, the current state of the art in network-centric warfare and an investigation into the science of semiotics for tools relevant to the sharing of situational awareness data visually across a network. Once this foundation has been laid, Chapter III will analyze current civilian efforts at capturing the utility of a network for situational awareness communications and identify successes and failures to date. Chapter IV will investigate the DOD's needs and compare them to the needs of DHS. Chapter IV will compare and contrast those tools available to the DOD with civilian needs, and more closely investigate their use of symbols as a part of network-centric communications. Chapter V will identify those precepts of the science of semiotics relevant to responders and compare them to the use of symbols in military applications. Chapter V will also discuss the shortcomings of previous attempts to create national symbols sets for the first responder community. Chapter V will apply the semiotic principles defined to discuss the concept of including contextually relevant information within a symbol set, drawn from the attributes of the asset itself. Chapter VI will conclude with recommendations for national policy on developing a contextually relevant visual language for networked communication of situational awareness.

II. LITERATURE REVIEW

"The common operating picture is used to overcome coordination and information management problems during emergency response."[10] This literature review is an attempt to develop a comprehensive understanding of common operating picture, the difficulties in communicating such, and current attempts to improve it. The literature is divided into seven distinct categories: First is the body of policy surrounding defining the need for a common operating picture. Second is the use of communication tools for developing situational awareness. Third is a description of the emergence of wireless networks for information exchange. Fourth is a depiction of the current state of the art for sharing a common operating picture in emergency operations. Fifth is an investigation of technology in development for situational awareness data exchange. Sixth is a review of semiotics and those principles that might apply to the sharing of situational awareness information with symbols. Finally, a comprehensive review of the non-classified military literature on the development and sharing of situational awareness on the modern network-centric battlefield is conducted to see if homeland security could be enhanced by lessons learned in warfare.

A. BODY OF POLICY

The National Response Framework (NRF) mandates the use of the National Incident Management System (NIMS) in response to incidents of all scales.[11] NIMS defines common operating picture as "An overview of an incident created by collating and gathering information—such as traffic, weather, actual damage, resource availability—of any type (voice, data, etc.) from agencies/organizations in order to support decision making."[12] The definition of common operating picture is embedded in

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[10] Jeroen Wolbers and Kees Boersma, "The Common Operational Picture as Collective Sensemaking," *Journal of Contingencies and Crisis Management* 21, no. 4 (2013): 186–99, doi:10.1111/1468-5973.12027.

[11] Federal Emergency Management Agency, *National Response Framework* (Washington, DC: Federal Emergency Management Agency, 2013), http://www.fema.gov/media-library/assets/documents/32230?id=7371.

[12] Federal Emergency Management Agency, *National Incident Management System* (Washington, DC: U.S. Department of Homeland Security, 2008), http://www.fema.gov/pdf/emergency/nims/NIMS_core.pdf.

the "communications and information management" component of NIMS and is a term interchangeable with "situational awareness" in many documents.[13] For the purposes of this thesis, "situational awareness" and "common operating picture" will be synonymous.

While the terms may be commingled in the literature, they are anything but clearly defined in the minds of crisis managers and responders. In 2007, the United States War College hosted a conference that included a workshop for local state and federal crisis managers entitled "Development and Dissemination of a 'Common Operational Picture' in Preparation, Response, and Recovery Operations between the Components of the Military and Civilian Authorities at All Levels of Government."[14] Participants were asked to define situational awareness one word at a time and had difficulty agreeing on definitions for each word.[15] The workshop conclusions were that the components of a common operating picture extend far beyond conditions currently existing within an incident. Sharing situational awareness includes tracking the past, present, and future status of myriad components that require input from a broad range of services representing a complex array of disciplines. For planning purposes, workshop attendees decided a common operating picture is best developed via the flow of data through a focal point, and that national effort should be directed at defining the standards for inputs and outputs to that focal point.[16]

NIMS was developed as a result of Presidential Policy Directive 5 (PPD-5), now succeeded by PDD-8,[17] which mandated the development of a national model for incident command. The NRF and NIMS are clear on the need for theater situational awareness. By defining it in the communications and information management component of NIMS, national policy defines the quality of shared situational awareness

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[13] Michael E. Stiso et al., "Building a Flexible Common Operational Picture to Support Situation Awareness in Crisis Management," in *Proceedings of the 10th International ISCRAM Conference*, 220–29, 2013, http://heim.ifi.uio.no/~ketils/kst/Articles/2013.ISCRAM-II.pdf.

[14] Jeffrey Copeland, *Emergency Response: Unity of Effort through a Common Operational Picture* (Carlisle Barracks, PA: U.S. Army War College, 2008), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA479583.

[15] Ibid.

[16] Ibid.

[17] George W. Bush, *Presidential Policy Directive 8* (Washington, DC: The White House, 2011).

by the quality of information flowing throughout an incident. How this information is managed and communicated varies greatly.

B. COMMUNICATIONS CREATE SITUATIONAL AWARENESS

Communications are simply defined as the imparting or exchanging of information.[18] Executive order has required that federal, state, and local governments are able to communicate continuously at all times.[19] The purpose of this requirement is to allow for the development of shared situational awareness across the range of involved responder organizations and individuals. Placing the correct information in the hands of decision makers in a timely manner is essential for response and recovery efforts. There are many case studies for both effective and ineffective communications and the impact each had on operations. Hurricane Katrina presented an excellent case of communication failures that contributed to undue death and destruction.[20] During Katrina, first responders were unable to communicate across the affected area to coordinate search and rescue operations for several reasons. Katrina damaged the land-based power and communication infrastructure that local responders relied upon, and as the incident progressed to the state and federal level, responders found their communications equipment to be incompatible.[21] Interoperable communications are described as a key component of sharing situational awareness data by NIMS.[22]

Communications interoperability is one of the most important issues facing local responders.[23] The DHS Office of Emergency Communications has identified technology as both the culprit and the cure for communications interoperability issues.[24] There is a

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[18] *Dictionary.com*, s.v. "Communications," accessed November 7, 2015, http://www.dictionary.com/browse/communications?s=t.

[19] Exec. Order No. 13618, 77 C.F.R. 133 (2012), https://www.hsdl.org/?view&did=716231.

[20] Meeds, *Communication Challenges during Incidents of National Significance: A Lesson from Hurricane Katrina*.

[21] Ibid.

[22] Federal Emergency Management Agency, *National Incident Management System*.

[23] Department of Homeland Security, "National Summary of Statewide Communication Interoperability Plans (SCIPs)," February 2009, https://www.hsdl.org/?view&did=782303.

[24] Ibid.

nationwide need for common communications technology, with common operating protocols that allow local responders to insert themselves into a command structure anywhere in the country and operate with little or no communications difficulty.[25] Since 2007, the states have developed statewide communications interoperability plans as part of their requirements for continued federal grant funding; these plans are limited to voice communications and do not address the exchange of data in other mediums.[26] Interoperable communications are fundamental to response; lack of interoperability has been linked to many responder deaths, including many responding to the World Trade Center on September 11, 2001.[27]

C. WIRELESS NETWORKS FOR COMMUNICATING SITUATIONAL AWARENESS

Analog, land-based mobile radios are the prevalent communication tool among first responders.[28] Radio failures in emergency circumstances are well documented, so much so that the National Fire Protection Association is drafting a new standard in an attempt to improve the reliability of radio hardware.[29] Mobile radios are designed to transmit voice in a simplex design, allowing one system user to transmit information and all other users to listen. A vast array of hardware and software is required to support public safety voice radio networks, including the licensure of radio spectrum, repeater towers, continuously powered infrastructure, and software to manage radio traffic. Most systems are designed to meet the continuity of operations outlined in Exec. Order No. 13681,[30] with secured perimeters, backup power supplies, and redundant systems.[31]

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[25] Department of Homeland Security, "National Summary of Statewide Communication Interoperability Plans (SCIPs)."

[26] Ibid.

[27] National Task Force on Interoperability, *Executive Summary, Why Can't We Talk*? (Washington, DC: U.S. Department of Justice, National Institute of Justice, 2005), https://www.ncjrs.gov/pdffiles1/nij/204348a.pdf.

[28] Office of Justice Program, National Institute of Justice, *Guide for the Selection of Communication Equipment for Emergency First Responders*, vol. 100 (Washington, DC: U.S. Department of Justice, 2002), https://www.hsdl.org/?view&did=1653.

[29] National Fire Protection Association, *NFPA 1802: Standard on Personal Portable (Hand-Held) Two-Way Radio Communications Devices for Use by Emergency Services Personnel in the Hazard Zone*, unpublished.

[30] Exec. Order No. 13618.

Traditionally, the transfer of data between responders occurred by voice, with one person speaking and everyone else listening. The arrival of the information age has delivered the ability to transfer larger volumes of data at far greater rates.

Wireless digital information exchange has passed through several stages of development and arrived at the 4th generation of Long Term Evolution (4GLTE).[32] There are five key reasons emergency responders traditionally face communication interoperability problems: limited funding, limited coordination and planning, and limited or fragmented available radio spectrum.[33] These same issues confront responders when attempting to share wireless digital data. FirstNet was authorized by the U.S. Congress in 2012 in an attempt to rectify all five of these issues.[34] The goal of FirstNet is to establish a nationwide broadband network accessible to all public safety services and allow the exchange of data at broadband speed at all times and in all locations, simultaneously. Funding for FirstNet is provided in part by the public auction of broadband spectrum to private industry, and through the sale of subscriptions to public safety organizations nationwide.[35] FirstNet will allow the myriad of data transfer solutions currently utilized by public safety to be moved off the commercial networks and onto a secured, hardened, protected broadband network.

D. STATE OF THE ART SITUATIONAL AWARENESS TOOLS

The creation of widely available, reliable wireless broadband service to first responders opens possibilities that were unheard of even a decade ago. Currently, numerous projects are underway attempting to harness this new broadband spectrum to improve situational awareness for responders across jurisdictions, borders, and

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[31] *Interoperable Emergency Communications: Does the National Broadband Plan Meet the Needs of First Responders? Hearing before the Subcommittee on Emergency Communications, Preparedness, and Response*, 111th Cong., 2 (2010).

[32] National Task Force on Interoperability, *Executive Summary, Why Can't We Talk*?

[33] Ibid.

[34] First Responder Network Authority, *FirstNet and Emergency Medical Services* (Reston, VA: First Responder Network Authority, 2015), http://www.firstnet.gov/sites/default/files/FirstNet%20EMS%20Fact sheet%20SPOC_150901.pdf.

[35] Ibid.

disciplines. A number of software services are being offered to public safety organizations utilizing commercial broadband networks. New World Systems, Tritech Software Systems, and Active 911 are just a few software vendors offering public safety dispatching and call management solutions, all of which rely on commercial broadband networks for wireless data exchange.[36] These types of solutions allow for the exchange of data between the various agencies with subscriptions to their services, which improve interoperability within the subscriber jurisdictions but leaves another national patchwork of proprietary systems. FirstNet will also require agency subscriptions but will have commonly defined nation-wide data standards, allowing for common, interoperable data sharing nationally.

Improving field situational awareness will require more than data interoperability. True improvements result in improved understanding of theater-wide response activities. This applies to small local incidents or nationally scaled events. Situational awareness needs will vary from one type of responder to another, and from one end of the command structure to the other. Creating a common operating picture in the information age will come not only from developing a network to transfer vast volumes of data but from finding methods to filter and share only relevant information most needed by the individual seeking it. Type 1 incident command teams may have a great need for satellite imagery of an entire state, while a local responder may only need to know where the next closest police car is, and whether or not they are on their way to the correct location.

With the increasing availability of broadband, and the approach of FirstNet, state of the art situational awareness data will be managed by software that allows for the layering of information by type, and filtered by settings defined by the end users roles and responsibilities.[37] A GIS allows the coupling of comprehensive tabular data to geographic features in the real world.[38] GIS is used today to plot maps and manage

[36] "Aegis Fire and EMS," accessed November 8, 2015, http://www.newworldsystems.com/Public-Safety/Solutions/Fire-EMS/; "Comprehensive, Easy to Deploy Public Safety Solutions," accessed November 8, 2015, http://www.tritech.com/products/perform; "How It Works," accessed November 8, 2015, https://www.active911.com/.

[37] Susan Lindell Radke, Russ Johnson, and Jeff Baranyi, *Enabling Comprehensive Situational Awareness* (Redlands, CA: Esri Press, 2013).

[38] Radke, Johnson, and Baranyi, *Enabling Comprehensive Situational Awareness*.

location-specific data in unlimited numbers of overlays. For example, a map of statewide counties might be overlaid with median incomes, or median ages, for a snapshot of these demographics across the state. These same principles can be applied to data relevant to public safety officials; for example, a GIS can take a table of hazardous materials manifests and plot them across a wide area by known locations. The density of hazardous materials storage can then be considered when working in these areas. GIS allows relevant responder information to be plotted across the response area, regardless of scale.[39] GIS provides a platform to embed lengthy lists of asset attributes in a geolocation, marked by a symbol or set of symbols. When coupled with wireless broadband, GIS becomes an excellent tool for real-time data exchange regarding assets, their attributes, and their actions.[40]

The Public Safety Communications Research Program (PSCR), organized under the U.S. Department of Commerce, has been assigned the responsibility of research and development for public safety communications affecting the next 20 years.[41] In their roadmap to the future, they identify location-based services as being the most critical component of communications technology for public safety.[42] These researchers state technological research and development funds should be directed at improved location-based services software and hardware to meet their objectives of optimized common operating pictures, data interoperability, improved mobility, and interoperability of nationwide networks. Of particular interest to PSCR is the development of high-resolution Z-axis locations (altitude), allowing for geolocation within tall structures, and the extension of high-resolution location-based services to rural areas. With these two improvements, a host of opportunities follow.

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[39] Radke, Johnson, and Baranyi, *Enabling Comprehensive Situational Awareness*.

[40] Ibid.

[41] Ryan Felts et al., *Public Safety Communications Research (PSCR) Program Location-Based Services R [and] D Roadmap* (Gaithersburg, MD: National Institute of Standards and Technology, 2015), http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1883.pdf.

[42] Ibid., 14.

E. SITUATIONAL AWARENESS TECHNOLOGY IN DEVELOPMENT

Improved high-resolution Z-axis locating systems, in conjunction with wireless networking, would allow for accurate geolocation within tall structures. Identifying the location of responders within tall structures and sharing those locations incident-wide would have a dramatic effect on incident common operating pictures. PSCR describes indoor route planning as an "underserved market" with great future potential when coupled with Z axis location.[43] This capability could be coupled with responder body sensors to allow for complete understanding of physical condition and location at all times, incident-wide. In the future, it is possible indoor route planning will extend to 3D mapping, allowing real-time imagery enhancement for responders with little or no visibility.

The upcoming availability of FirstNet and networked management of assets equipped with location-based sensors represents a national opportunity. FEMA has already identified many of the types of assets and their attributes of interest to national response.[44] The technology exists today to allow for the geolocation of those resources and the communication of those locations via wireless data exchange with a GIS server. When high-resolution geolocation is combined with FEMA typing and overlaid on a GIS, we approach a new age in situational awareness and the sharing of a common operating picture among responders. The advent of FirstNet expands the possibilities to include the two-way flow of situational awareness data to and from a networked data-hub, which continuously updates statuses and conditions on the ground in real time, thereby creating an optimized common operating picture for use by each unique user within public safety.

[43] Felts et al., *Public Safety Communications Research (PSCR) Program Location-Based Services R [and] D Roadmap*, 20.

[44] "FEMA's Tier 1 National Resource Typing Definitions," March 2009, https://www.fema.gov/national-incident-management-system/national-integration-center-resource-management.

F. SEMIOTICS AND INFORMATION SHARING

Semiotics is the study of visual communication through signs and symbols.[45] Human beings have been using symbols and signs since the beginning of recorded history, and in fact, the earliest human histories are preserved as glyphs etched in stone.[46] When considering human communication, there is a tendency to separate written and verbal communication from imagery, which is often relegated to the status of artwork.[47] It is often presupposed that for visual communication to be considered effective, it must contain the standard prose conventions of the written word. Thus, visual communication is often erroneously considered a less effective communication medium than verbal or written information exchanges.[48]

However, there are almost limitless possibilities for symbolized communication. There are over 60,000 hues and shades of discernable colors, which can be combined in limitless patterns, formed into vast arrays of shapes, and overlaid onto countless textures.[49] This virtually endless potential stands in stark contrast to the limits of "linear, and irreversible chain of words in verbal language."[50] Saint-Martin describes the singular unit of visual communication to be the "colorme," which when considering the biology of the human eye, must be large enough to be perceived, but small enough to "permit an efficient realization."[51] The colorme may vary within the defined limits of size with the limitless set of colors, shapes, and textures to provide a wide range of visual stimuli. Single colormes may then be combined or grouped to convey a vast amount of information, often in a nonlinear fashion. Single colormes can be constructed to convey

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[45] Dictionary.com, s.v. "Semiotics," accessed June 12, 2016, http://www.dictionary.com/browse/semiotics?s=t.

[46] John Baines, "Communication and Display: The Integration of Early Egyptian Art and Writing," *Antiquity* 63, no. 240 (September 1989): 471–82.

[47] Ibid.

[48] Fernande Saint-Martin, *Semiotics of Visual Language* (Bloomington, IN: Indiana University Press, 1990).

[49] Ibid., 3.

[50] Saint-Martin, *Semiotics of Visual Language*.

[51] Ibid., 6.

the equivalent of an entire written passage.[52] For the purposes of this thesis, Saint-Martin's single colorme will be described as a symbol.

Gitelman and Jackson state that "data are mobilized graphically."[53] Symbols then can become representations of complex underlying data. The manner in which symbolized data is presented lends credence to its perceived authenticity and objectivity.[54] Kennedy et al. argue four conventions are required to achieve these perceptions: Two-dimensional viewpoints, clean layouts, geometric shapes and lines, and the inclusion of data sources.[55] They further define the term "convention" within semiotics as "a symbolic or social practice that is shared, readily understood, and widely accepted by members of a cultural group."[56] These conventions create context for the interpretation of symbols for members of a cultural group.

Technology has always played a role in the recording and delivery of symbols. Early depictions of contextualized data occurred in the 1600s. Kennedy et al. note the arrival of the color printing press as the pivotal moment in the portrayal of symbolized data, allowing the creation of complex colored geographic maps and cartograms.[57] Color has long been a powerful tool for differentiating symbols and the technology for delivering full-color symbolized information has continued to advance through the centuries. While society may now consider a full-color high definition display to be commonplace and relatively unremarkable, the technology that makes such a display possible continues to change the manner in which we communicate.

[52] Saint-Martin, *Semiotics of Visual Language.*

[53] Steven Jackson and Lisa Gitelman, *"Raw Data" Is an Oxymoron* (Cambridge, MA: The MIT Press, 2013).

[54] Helen Kennedy et al., "The Work That Visualization Conventions Do," *Information, Communication & Society* 19, no. 6 (2016): 715–35.

[55] Ibid., 723.

[56] Ibid., 717.

[57] Ibid., 718.

The visual representations of cartography include lines, points, and polygonal shapes.[58] Whysel states cartography can and should be adapted for use by emergency responders to identify geospatial entities relevant to them.[59] Cartographic depictions of items specifically selected to create context for a specific population are among the "cartographic pragmatics" of the map.[60] Cartographic pragmatics for first responders can include a wide range of information that may be general in nature, like traffic patterns or locations of medical facilities, to highly specific information like access and egress points for a specific structure. Maps used for emergency response require careful design to ensure accuracy and clarity.[61] Within these maps, symbols must be used to depict the location of features relevant to the response context. As the technology allowing interactive mapping for first response has advanced, many early adopters have undertaken efforts to develop symbols useful for this purpose, leaving a large range of unique and varying symbols for emergency management nationwide.[62] Whysel notes the efforts of Pennsylvania State University in cooperation with the American National Standards Institute (ANSI) to develop a common useful emergency management symbols set to eliminate the interoperation confusion that results from inconsistent symbology.[63]

The varying range of developed symbols sets for emergency response and management have been identified as an interoperability weakness nationwide.[64] The 2006 ANSI standard developed a national symbol set but it has been poorly received within the response community.[65] ANSI finds a very low adoption rate of the symbol set

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[58] Norreen Y. Whysel, "Semiotics, Mapping, and Emergencies" (slides, semiotics web and information architecture meetup, New York Public Library, November 1, 2014), http://whysel.com/portfolio/semiotics-and-emergency-management/.

[59] Ibid.

[60] Ibid.

[61] Ibid.

[62] Ibid.

[63] Ibid.

[64] Anthony C. Robinson, Alan M. MacEachren, and Robert E. Roth, "Challenges for Map Symbol Standardization in Crisis Management," in *7th International ISCRAM Conference, Seattle, WA* (University Park, PA: GeoVISTA and The Pennsylvania State University, 2010), http://www.geovista.psu.edu/publications/2010/222-Robinson_etal.pdf.

[65] Ibid.

within responder communities and ongoing development of unique symbols outside of their standard. A survey of California firefighters found only seven of the 28 symbols developed for firefighting events produced a comprehension rating better than 75 percent.[66]

ANSI symbols are point symbols, meaning they identify a single resource as a point, and when placed in the context of a map they can be correlated to a location. Robinson, MacEachren, and Roth surveyed those communities of responders who were using resource symbols but had opted against the ANSI 415 standard to identify their preferred symbols set. Responder communities queried included the U.S. Coast Guard, the U.S. Fire Administration, the National Operations Center, FEMA, and the Domestic Nuclear Detection Office. In all cases, respondents stated they were using an "in house" mix of custom-designed symbols sets. Robinson, McEachren, and Roth report respondents did not find the ANSI standard "matched their operational perspective."[67] The ANSI symbols could not provide the needed cartographic pragmatics; in other words, they failed to provide needed context.

G. SITUATIONAL AWARENESS IN NETWORK-CENTRIC, GEOLOCATED MANEUVER WARFARE

The term "fog of war" is generally attributable to Prussian Soldier Carl von Clausewitz, although he never used the phrase.[68] Wartime fog is described as having several component parts, many of which are also directly attributable to emergency response operations. Clausewitz forges a term to encompass the difficulties of waging war: Friction, which he defines as "the force that makes the apparently easy so difficult."[69] The components of friction include uncertainty, fluidity, disorder, and

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66 Robinson, MacEachren, and Roth, "Challenges for Map Symbol Standardization in Crisis Management."

67 Ibid.

68 Paul C. Hudson and Jeffrey A. Rzasa, "Knowledge Visualizations: A Tool to Achieve Optimized Operational Decision Making and Data Integration" (master's thesis, Naval Postgraduate School, 2015), http://calhoun.nps.edu/handle/10945/45877.

69 U.S. Marine Corps Staff, *Warfighting*, first printing (Provo, UT: Renaissance Classics, 2012).

complexity,[70] all of which are also present in emergency response. The parallels between warfare and emergency response are numerous. In generations past, it might have been defensible to say that responders did not face an organized enemy combatant, but that too is changing. Today's responders face natural and man-made disasters, as well as organized murderous enemies of domestic tranquility.

United States Marine Corps doctrine identifies uncertainty, fluidity, disorder, and complexity as inherent parts of warfare, and each can be also be found in homeland security operations. Uncertainty in warfare includes the entire unknown, including those about your enemy, the environment, and even friendly forces.[71] Domestic responders face similar uncertainty with every alarm, from construction uncertainty in structural fires to behavioral uncertainty in law enforcement actions. Fluidity in warfare is the ever evolving battlespace, often unique when viewed singly, but related to events unfolding globally.[72] Responders face fluid events that can evolve into larger or multiple incidents. Racial tension in one part of the country may create unique but related homeland security events in other parts of the city, state, or country.

Disorder is described as an inherent characteristic of war, caused by unclear or incomplete information, miscommunication, and unforeseen events and miscommunication.[73] Domestic response inherently faces all those same obstacles, as cases of each are well documented in all types and scales of homeland security incidents. Complexity in warfare is a result of the myriad of working parts, supported not by a single consciousness but by the consciousness of many, many combatants. The various elements of a warfighting force assigned myriad responsibilities must coordinate and communicate large amounts of data to interoperate effectively to achieve an objective.[74] The mitigation of homeland security incidents is also driven by the cognition of a myriad of minds, despite the routine presence of a command structure. This complexity is

[70] U.S. Marine Corps Staff, *Warfighting*, 3–8.

[71] Ibid., 4.

[72] Ibid., 5.

[73] Ibid., 6.

[74] Ibid., 7.

compounded as the incident scale grows, as domestic responder silos do not benefit from a national executive board of joint leadership as found in the military's Joint Chiefs of Staff. Complexity abounds in the domestic response arena.

Armed forces were, perhaps, the original customers of contextually relevant map symbols. Maneuver warfare, by definition, requires those in command to have a well-developed understanding of their resources, the location of those resources, and the best possible estimation of the same data for enemy forces. Simply collecting the right information does not create situational awareness. Driesslein said, "to have situational awareness, the right information must be delivered to the right people, at the right time, in the right way."[75] Military systems have advanced in this manner, attempting to connect, filter and layer information in a way that creates an immediately relevant context for warfighters. Driesslein goes on to state, "Good situational awareness is highly context dependent."[76] Developing and reporting on battlefield situational awareness has progressed in tandem with the development of information sharing technologies. To facilitate the best possible common operating picture and battlefield situational awareness, the U.S. armed forces today utilize a dazzling array of scalable information networks across their geographically and contextually diverse battlespaces. Despite all the advances in communication technology, very much like Napoleon's ancient command post, often a map is still needed to provide context in these complex information systems.

Data and communications networks are critical to military operations, so much so that they are carried into battle as a matter of routine. The continuous presence and constant advancement of communications networks in the battlespace have led to the term network-centric warfare,[77] which suggests the growing dependency of warfighters on information systems. Baskarada identifies a cascade of advantages created by

[75] Jonathan Clarke Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations" (master's thesis, Naval Postgraduate School, 2015), https://calhoun.nps.edu/handle/10945/45843.

[76] Ibid., 9. [emphasis added]

[77] Sasa Baskarada, "Towards a Semiotic Information Position Framework for Network Centric Warfare," in *16th International Command and Control Research and Technology Symposia (ICCRTS)*, Québec City, Canada, 2011, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2142975.

network-centric warfare. Firstly, "a robustly networked force improves information sharing," which enhances the quality of information and shared situational awareness; secondly, "shared situational awareness enables self-synchronization."[78] These factors combined dramatically improve mission effectiveness.[79]

Military communications networks vary in size and scope, and from one branch of service to another. Networks scale in size from global satellites to vehicle-mounted, providing a range of resolutions. A wide variety of decision support systems run on these networks to improve the situational awareness of decision makers. Information on several of these decision support systems resides in the public domain including Blue Force Tracker (BFT-2), Link 16, and Force XXI Battle Command Brigade and Below (FBCB2).

The U.S. Army Catalog of weapons systems describes FBCB2 as an automated tool for dissemination of locations of friendly and known adversarial forces, as well as graphical depictions of commander's intentions.[80] FBCB2 deployment is dependent on the presence of several other systems in the battlespace but in particular the Warfighter Information Network—Tactical (WIN-T), which is a field deployed wireless information network consisting of a range of wireless technologies.[81] FBCB2 is a land-based platform that locates resources, symbolized and overlaid on a series of tactical maps. FBCB2 required vehicle-mounted hardware; thus, the resolution of distributed resources does not extend beyond vehicle to smaller resources like dismounted soldiers.

The U.S. Air Force and U.S. Navy operate a networked decision support system known as Link 16. Its purpose is to manage the battlespace and maintain "shared situational awareness in operations."[82] Link 16 is described as a "system of systems" capable of dividing and networking the battlespace into up to 127 different ad-hoc data

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[78] Baskarada, "Towards a Semiotic Information Position Framework for Network Centric Warfare."

[79] Ibid.

[80] United States Army, *Weapon Systems 2012 America's Army: The Strength of the Nation* (Arlington, VA: United States Army, 2012).

[81] Ibid., 316–320.

[82] Myron Hura et al., *Interoperability: A Continuing Challenge in Coalition Air Operations* (Santa Monica, CA: RAND Corporation, 2000), http://www.rand.org/pubs/monograph_reports/MR1235.html.

networks that communicate with shared servers for geolocation of resources on land, sea, and air.[83] While the information must contain some Z-axis information for altitude, Link 16 also utilizes two-dimensional tactical battlespace maps with symbols overlaid for situational awareness data. Link 16 is also limited to being vehicle-borne, typically by aircraft, and does not include a resolution for resources as small as unmounted soldiers.[84]

Both FBCB2 and Link 16 have been designed to utilize wireless radio networks comprised of ground-mobile base stations (in the case of FBCB2), seaborne radio platforms, airborne radio platforms, and satellite networks in orbit utilizing a range of bandwidth spectrum. The systems share a common purpose, to share situational awareness data including identification, location, activity, and status of a wide array of forces deployed in and around the battlespace. The complex array of potential participants includes forces from the various U.S. military branches, as well as the various branches of allied nations and intelligence about opposing forces. This complexity is closely mirrored by the vast array of responder groups that might engage in mitigation of domestic homeland security incidents.

Hardware requirements for both FBCB2 and Link 16 are too large for man-portable utilization. While outside the scope of this thesis, it is worthwhile to note that both the U.S. military and the various responder communities have need of low-cost, low profile man-portable situational awareness data to track individual human resources. Currently in the research and development phase at the Naval Postgraduate School is a mobile ad-hoc network (MANET) and associated hardware for tracking situational awareness data within small unit operations.[85] Driesslein's research has found a man-portable lightweight sensor network connected to a low-cost computer known as Raspberry Pi that can collect and transmit data relevant at the squad level. Driesslein's system in development is an answer to the Defense Advanced Research Projects Agency's (DARPA) Squad X project, which calls for solutions to squad-level problems

[83] Hura et al., *Interoperability: A Continuing Challenge in Coalition Air Operations*.

[84] Ibid.

[85] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations."

like precision engagement, non-kinetic engagement, squad sensing, and squad autonomy.[86]

While the objectives for military squads are set in the combat context, their tasks can be easily correlated to those of domestic responders. Squad objectives described by DARPA include resource optimization and synchronization of squad activities down to the individual rifleman.[87] The Squad X project seeks to enable networked information sharing down to the single human resource, so all warfighters in the field have access to current situational awareness data. These needs directly correspond to the needs of domestic responders during homeland security incidents of all scales. Situational awareness sharing down to single responder resolution is outside the scope of this thesis but will be an essential part of future research and development for the DHS. All these technologies depend on location orientation and situational awareness data exchange over a wireless network, set in the context of their area of operations, overlaid on a tactical map. Development of effective symbols capable of conveying the context of this dynamic environment is essential for military and civilian operations in network-centric environments.

[86] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 24.

[87] Christopher Orlowski, *Squad X Experimentation Program* (Arlington, VA: DARPA, 2016), http://www.darpa.mil/attachments/Squad_X_Proposers_Day_DARPA_SQUADX_FINAL.pdf.

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III. CIVILIAN APPLICATIONS FOR SITUATIONAL AWARENESS SHARING

A. COMMUNICATING SITUATIONAL AWARENESS IN THE HOMELAND

Homeland security responders face many of the same challenges as warfighters, yet the diverse nature of American emergency response networks has produced a patchwork of methodologies and technologies for managing situational awareness. There are over 27,000 fire jurisdictions,[88] 18,000 state and local law enforcement agencies,[89] and over 9,500 emergency medical service provider services not affiliated with a fire department (third services)[90] nationally. There are also myriad federal response assets managed by the DHS's 22 subordinate agencies, as well as National Guard assets in each of the 50 states. The potential for complexity of mixed jurisdictional assets at any given homeland security incident is difficult to overstate. When compared with the four branches of the armed services, it is easy to understand how efforts at developing situational awareness might be more diverse and less consistent domestically than within the DOD.

1. Land-Based Mobile Radio Networks

The earliest electronic communications came in the form of the telegraph, which connected humans electronically for the first time. Obviously, that was a cumbersome system of communication but when your alternatives were U.S. post or Pony Express, the telegraph was an enormous advance. Wiring a telegraph was limited to simplex communications: one sender while receivers remained silent during delivery. Interestingly, despite the magnitude of advances in electronic communications, the vast

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[88] "National Fire Department Census Quick Facts," accessed August 18, 2016, https://apps.usfa.fema.gov/census/summary.

[89] "Census of State and Local Law Enforcement Agencies, 2008," accessed August 18, 2016, http://www.bjs.gov/index.cfm?ty=pbdetail&iid=2216.

[90] National Highway Traffic Safety Administration, *EMS System Demographics* (Washington, DC: National Highway Traffic Safety Administration, 2014), https://www.ems.gov/pdf/National_EMS_Assessment_Demographics_2011.pdf.

majority of homeland security responders are still subject to that same limitation. A modern land-based mobile radio network in use by emergency services can come in a variety of very high frequency (VHF) or 800 megahertz (mHz) configurations with trunking technology and meet all the current requirements for narrow-band wireless communications; but one critical feature that does not change is the nature of simplex voice exchange: One talker, multiple listeners. Anyone wishing to interject information into a simplex radio exchange must wait for a break in the conversation for their turn to speak.

These radio networks are a patchwork of systems that often butt up to or overlap one another, but are often unable to exchange information between them.[91] Homeland security responders have grown to depend on these networks for situational awareness data exchange, with doctrine for the conveyance of "short reports"[92] and situational updates that are generally described by national policy but often vary wildly across the vast array of jurisdictions. The *Model Procedures Guide for Fire Fighting Incidents* has extensive elaborations about the manner in which users will identify themselves by radio, the format of messages, and the order in which users will prioritize themselves.[93] Despite extensive guidance on the subject, the failure of voice communications via radio is attributed to firefighter injuries and deaths on a continual basis.[94] Still, a great deal of national emphasis is placed on improving voice radio communications technologies that will always be limited to simplex communications,[95] and while voice communications will surely always play some role during homeland security incidents, this thesis suggests a better communications tool. Homeland security responders have a need for a vast array

[91] National Task Force on Interoperability, *Executive Summary, Why Can't We Talk*?

[92] International Fire Service Training Association, *Incident Command System (ICS) Model Procedures Guide for Incidents Involving Structural Fire Fighting, High-Rise, Multi-Casualty, Highway, and Managing Large-Scale Incidents Using NIMS-ICS* (Stillwater, OK: Fire Protection Publications, 2007).

[93] Ibid.

[94] Fernanda Santos, "Report Cites Poor Communication Before Firefighters' Deaths in June," *The New York Times*, September 28, 2013, http://www.nytimes.com/2013/09/29/us/report-cites-poor-communication-before-firefighters-deaths-in-june.html.

[95] Space and Advanced Communications Research Institute, *White Paper on Emergency Communications* (Washington, DC: George Washington University, 2006), https://www.hsdl.org/?view&did=688932.

of information to create situational awareness and the limits of land-based mobile radio networks create a bottleneck in that information flow.

2. Cellular Networks

The advent of cellular telephones opened a new era in voice communications for homeland security responders. Cellular networks delivered duplex communications to emergency workers in the field. For the first time, responders were able to have an open conversation via cellular telephone, which allowed both speakers to exchange information without the linear wait of simplex conversations. Known as duplex communication, it is a more effective and comfortable modality, but there are also limitations to the use of cellular communications in homeland security response. Responders working at geographically diverse locations across an incident scene routinely need situational awareness data to be shared across the entire incident simultaneously, which is not practical with cellular voice across large user groups. Voice teleconferencing is an example of duplex communications across larger user groups and is an excellent illustration of some of the pitfalls: Many users must be muted or silent while information is exchanged; otherwise, the volume of voice data becomes unintelligible noise, and as more users are added, the more this problem amplifies.[96]

Cellular networks are currently private, for-profit enterprises. Homeland security responders access them as paying clients of a commercial service, and as such, are often treated as any other customer would be. Cellular networks have limitations on the number of concurrent users and are known to fail when overloaded with traffic.[97] The United Kingdom has managed this reality with legislation requiring priority access to cellular networks for first responders, generally known as "access overload control" (ACCOLC) legislation.[98] Despite the application of ACCOLC laws, when stressed by national

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[96] "Disadvantages of Video Conferencing," accessed August 18, 2016, http://www.video-conferencing-guide.org/disadvantages-of-video-conferencing.html.

[97] Meeds, *Communication Challenges during Incidents of National Significance: A Lesson from Hurricane Katrina*.

[98] Department of Homeland Security, Lessons Learned Information Sharing, *Emergency Communications: Distributing Pagers to Emergency Responders for a Mass Casualty Incident* (Washington, DC: Department of Homeland Security, n.d.), https://www.hsdl.org/?view&did=779837.

security incidents British cellular networks are still known to fail responders, requiring backup communication plans.[99] The United States is considering ACCOLC as part of a federal legislation package for first responders but there are currently no federal requirements for such; any ACCOLC granted by cellular carriers in America is done so as a result of state legislation or on a voluntary basis.[100] The nature of the commercial cellular network is such that it provides a valuable tool to responders but is unreliable when needed most.

3. Wireless Data Networks

Wireless data networks followed cellular voice networks, utilizing much of the same infrastructure. While not to the extent that military forces have begun to develop network-centric warfare on the backbone of proprietary military field mobile systems like WIN-T, homeland security responders have begun to utilize these wireless data networks to create elements of a network-centric response. With no national standards, these elements are developing independent of one another and may result in the same patchwork of incompatible systems that plague the homeland today. This is unsatisfactory and does not meet the national effort towards improved interoperability between the various responder silos.

Wireless data networks are subject to many of the same vulnerabilities of cellular voice networks, including overload and failure during homeland security incidents. However, the value of escaping simplex and duplex voice communications exceeds the risk of system failure and most homeland security wireless data networks rely on commercial infrastructure. This relationship is effective while the networks are running smoothly and there are no impacts to responder operations. Ever-increasing consumer demand for data does create a competitive environment for physically limited wireless bandwidth. With little profit in supplying wireless data to emergency services, there are

[99] Department of Homeland Security, Lessons Learned Information Sharing, *Emergency Communications: Distributing Pagers to Emergency Responders for a Mass Casualty Incident*.

[100] *Interoperable Emergency Communications: Does the National Broadband Plan Meet the Needs of First Responders? Hearing before the Subcommittee on Emergency Communications, Preparedness, and Response*.

cases where connectivity is cited as a principle cause for 911 emergency dispatching system failures when those systems depend on cellular data connectivity.[101] Wireless data providers have no mandated incentive to address the connectivity issues of public safety over any other consumer groups, and so public safety connectivity largely resides at the mercy of a for-profit corporation. Relying upon commercial cellular networks for situational awareness during significant homeland security incidents has proven problematic at best and dangerous at worst.[102] As does the military, domestic responders require a resilient wireless data network that can be depended on to provide reliable data coverage under adverse conditions. Continuity of service is the only way the advantages of networked systems can be fully realized during significant homeland security incidents. As in warfare, friction impacts emergency operations and all its component parts; a wireless network for responders must be engineered to reduce friction.

4. FirstNet

In 2012, the Middle-Class Tax Relief and Job Creation Act became law. Contained within the act was the first effort toward the funding and creation of a nationwide, interoperable, hardened broadband network for use by homeland security responders.[103] Communications interoperability failures during the September 11, 2001 terrorist attacks and again during Hurricane Katrina are routinely cited as the driving impetus behind the legislative push for such a network.[104] FirstNet was formed in the act to build, deploy, operate and maintain a national public safety broadband network (NPSBN) upon which interoperable software could run seamlessly nationwide.[105] In general, the FirstNet system was originally envisioned to be a disaster-hardened wireless network that reached all corners of the nation, including dense urban centers and rural

[101] "Everett to Stick with Problematic Emergency Dispatch System," May 15, 2016, http://myeverett news.com/2016/05/15/everett-stick-problematic-dispatch-system/.

[102] Meeds, *Communication Challenges during Incidents of National Significance: A Lesson from Hurricane Katrina*.

[103] First Responder Network Authority, *Public Safety Advisory Committee Fact Sheet*.

[104] *Interoperable Emergency Communications: Does the National Broadband Plan Meet the Needs of First Responders? Hearing before the Subcommittee on Emergency Communications, Preparedness, and Response*.

[105] Ibid.

areas, independent of any commercial network(s) available in the same markets.[106] Funding for the creation of the NPSBN is provided through the auction of publicly-held electromagnetic spectrum bandwidth rights to private enterprise.[107] The act added an additional 10 mHz of bandwidth within the 700 mHz spectrum dedicated to public safety purposes. This was in addition to the 14 mHz of spectrum already allocated in that bandwidth bringing the total available 700 mHz spectrum to 24 mHz. The 700 mHz range is valuable as it is an effective bandwidth for the broadcast of wireless broadband data and is highly desirable to private network providers.[108]

Since the inception of the original plan, some have questioned the sufficiency of this allocation to meet the current and future spectrum needs of public safety. Congresswoman Laura Richardson (CA) is the chairwoman of the U.S. House Homeland Security Subcommittee on Emergency Communications, Preparedness, and Response. She held hearings on the topic in July 2010 and received testimony from several experts who suggested that a dedicated independent wireless network may not be the best model for public safety.[109] Some public safety officials reported concerns about network capacity with such an allocation, yet a study by the Federal Communications Commission reported that when the new spectrum allocation was summed with existing public safety spectrum, there was over 97 mHz now dedicated solely to that purpose and represents over 25 times more spectrum per user than is available to private service subscribers.[110]

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[106] *Interoperable Emergency Communications: Does the National Broadband Plan Meet the Needs of First Responders? Hearing before the Subcommittee on Emergency Communications, Preparedness, and Response*.

[107] Federal Communications Commission, *The Public Safety Nationwide Interoperable Broadband Network: A New Model for Capacity, Performance and Cost* (Washington, DC: Federal Communications Commission, 2010), https://www.fcc.gov/pshs/docs/releases/DOC-298799A1.pdf.

[108] Ibid.

[109] *Interoperable Emergency Communications: Does the National Broadband Plan Meet the Needs of First Responders? Hearing before the Subcommittee on Emergency Communications, Preparedness, and Response*.

[110] Federal Communications Commission, *The Public Safety Nationwide Interoperable Broadband Network: A New Model for Capacity, Performance and Cost*.

Several alternate models for the creation of an NPSBN have been considered since FirstNet was authorized, including the possibility of some or all public safety data being routed through an expanded private infrastructure with priority access, similar to the ACCOLC features of British traffic on their privately-held networks.[111] The technical and policy feasibility of adequate priority access is the subject of current debate and no decision has been reached on the exact design of the NPSBN at the time of this writing. However, it is clear that a new, hardened wireless network dedicated to homeland security functions is on the horizon and supports the continuation of efforts to develop interoperable public safety tools for use on such a network. The ability to communicate exponentially larger volumes of situational awareness data on an NPSBN when compared to the limitations of voice on legacy land-based mobile radio networks or cell phones requires the development of a consistent and easily understood language for interoperation in the new network-centric response environment. Critical to this thesis is the understanding that regardless of the final configuration of FirstNet, it will provide a resilient backbone for the communication of interoperable situational awareness data among responders but no part of the project addresses how that communication will occur or what form it will take.

5. Broadband Tools

Wireless broadband networks allow vastly larger amounts of data to travel through the same electromagnetic spectrum than traditional radio networks. While spectrum alone does not determine network capacity, the presence of a wireless infrastructure dedicated to public safety opens the floodgates for information flow within homeland security workspaces. Currently, the reliability issues described for private data networks hamper responders and retard the utilization of information tools commonly used by consumers. While there is steady advancement of utilization of wireless technology in public safety, it is sporadic and inconsistent. National policy does not yet address the methods by which increasingly networked homeland security responders will utilize the improved rate of information flow.

[111] Federal Communications Commission, *The Public Safety Nationwide Interoperable Broadband Network: A New Model for Capacity, Performance and Cost*.

When considering the impact of broadband on a response force that is accustomed to sharing situational awareness information via verbal reports on simplex or duplex voice systems, the possibility of equipping responders with larger volumes of vastly better decision-making information is striking. National efforts today should be focused on methods of representing, sorting, filtering, and layering that information so the network-centric response can realize its potential without overloading users. Just as Driesslein states for warfighters, the mere presence of information does not create situational awareness; useful data must be delivered to the right people in the right time to create it.[112] While new digital tools will be available to future, broadband-equipped homeland security responders, it is critical that they are developed in such a way that they apply Driesslein's objectives.

The bandwidth provided by developing wireless data networks, combined with the information traffic management of a computer network, opens a new era in public safety communications. While many efforts are underway to develop tools for communicating situational awareness, they are occurring in pockets, with no national standards on how that will occur. There is currently no national guidance on responder use of streaming video, video conferencing or sharing live closed-circuit video feeds with field units. There is also a plethora of externally developed data feeds with information that is relevant to responders like traffic, weather, social media, and more. If managed correctly, much of this data can be used to add context to homeland security events, but if mismanaged, it threatens to create information overload.

B. MAPPING SITUATIONAL AWARENESS

To build situational awareness, responders must answer three essential questions that bear a striking resemblance to General Dunn's questions for warfighters: "Where am I?" "Where are my forces and other friendly forces?" and "where is the enemy and what

[112] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 26.

is the best route to attack him?”[113] With very little imagination, these situational awareness questions from warfare can be adapted to a homeland security response: Where am I? Where are other responders? Where is the problem, and what is the best route to solving it? Whether it be warfare or a homeland security incident, a map is a foundational tool upon which the answers are developed.[114]

Maps depict features of the environment graphically in a way that readers can orient themselves within for location awareness. Maps come in all forms, from depictions of the continents to floorplans of buildings to the layout of biological systems within a single cell. Digital maps display these same graphical depictions in an environment that make them more user-friendly, allowing the user to pan and zoom and overlay layers of data that can be related to specific locations on the map. These very sophisticated mapping tools are known as GIS and have become so compact and user-friendly that they are a part of most modern portable devices and can be used by laypersons with ease.

Google Maps is a fine example of a user-friendly GIS with selectable layers for the creation of manageable situational awareness information. Layers include streets, aerial imagery, traffic, and data points like attractions and specific addresses. Users can change the focus of their view of Google Maps by changing the assumptions about their mode of transport: vehicle, bicycle, or pedestrian. American smartphone users now take these capabilities for granted, but equal services are slow to arrive for homeland security responders. Publicly-available mapping tools can be accessed by responders but there is currently no option to change the focus of the map view to providing public safety specific context. Several commercial, non-profit, and government vendors are attempting to fill this void by developing GIS-based tools for sharing incident information that answer the three essential questions of situational awareness.

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[113] Richard J. Dunn, III, *Blue Force Tracking—The Afghanistan and Iraq Experience and Its Implications for the U.S. Army* (Reston, VA: Northup Grumman, 2003), http://www.northropgrumman.com/aboutus/analysiscenter/documents/pdfs/bft-afghanistan-and-iraq-exper.pdf.

[114] Bill Meehan, “Access, Awareness, and Analysis—All in One Location Platform,” ArcWatch: GIS News, Views, and Insights, July 2016, http://www.esri.com/esri-news/arcwatch/0716/access-awareness-and-analysis-all-in-one-location-platform.

The foundation of a GIS is a map that makes reference to the real world, with the placement of tabular data within the map extent to relate data to real-world geography. Any tabular data that can be related to a specific place can be displayed by a GIS. The scales of various GIS maps can range from architectural to global, with data overlaid to depict things like population demographics or the location of all street signs within an area; the sorting, filtering, and layering of data within a GIS produce unique views for users.[115] The most critical issue addressed by any GIS is what to represent and how to represent it.[116] National policy has not yet answered these two questions for homeland security responders.

Data can be displayed on a GIS map in two formats, rasters and vectors.[117] Most GIS maps in use today use a combination of both, and further break vectored data into points, lines, and polygons. Typically, vectored data is overlaid upon a raster map to provide the best representation of reality. Several techniques can be applied to simplify the features of a GIS map for ease of understanding and to avoid information overload. These generalization techniques include simplification, smoothing, collapse, aggregation, amalgamation, merging, refinement, exaggeration, enhancement, and displacement.[118] While all these principles have been defined in GIS science, they represent a series of cognitive compromises that can vary from one application to another and largely depend on the intended use of the GIS. Defining these compromises will be essential for national policy surrounding network-centric response mapping applications.

Critical to this thesis is the understanding of the manner in which a GIS manages data associated with features on the map. Behind each map feature is a table of data used to define the characteristics of that feature; this table is known as an attribute table.[119] Polygons are used to depict data with volume, like jurisdictional boundaries or the perimeters of structures. Examples of attribute data for structures depicted as a polygonal

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[115] Paul A. Longley et al., *Geographic Information Systems and Science* (Hoboken, NJ: John Wiley & Sons, 2010).

[116] Ibid., 81.

[117] Ibid., 88.

[118] Ibid., 92.

[119] Tim Ormsby et al., *Getting To Know ArcGIS* (Redlands, CA: ESRI Press, 2010).

shape could include things like number of stories, year built, address number, and virtually any other detail that can be stored in an electronic table. Line shapes in a GIS include things like rivers or roads and attribute data could include attributes like names, volumes of water flow, speed limits, and the like. Points are used to depict single location items with no relative volume like single address points, intersections, and locations of specific resources. Points are used to depict the answer to the “where am I?” question for resources in military systems like Link 16 or FBCB2 and homeland security applications like Next Generation Incident Command (NICS). Data contained in attribute tables defines the details of represented items, and when the data is numerical, it allows for complex statistical comparisons between represented features. For homeland security purposes, the attribute table is a critical feature of situational awareness sharing, as it where contextual data is stored, allowing an improved understanding of the feature and its relationship to other mapped features visually, with no need for verbal exchange.

Mapped features may be represented by a host of symbols and varied endlessly using semiotic principles. When shared via a network, a GIS is a map-based platform for communicating vast volumes of location and contextual attributes, creating geolocated semiotic communication that occurs instantly across networked users. A GIS is not constrained by the push-to-talk limits of voice communication and can make use of the full range of human visual sensory inputs defined by semiotics. Homeland security responders must define best principles and practices for this new method of communication, so we develop a language that is easily understood by all network-centric responders.

C. STATE OF THE ART HOMELAND SECURITY GIS TOOLS

1. Next Generation Incident Command

NICS, also known as SCOUT (Situation Awareness and Collaboration Tool) in California State,[120] is networked incident management software built around a mapping

[120] California Governor’s Office of Emergency Services, *Situation Awareness & Collaboration Tool (SCOUT) FAQ Sheet* (Mather, CA: California Governor’s Office of Emergency Services, 2016), http://www.caloes.ca.gov/RegionalOperationsSite/Documents/2016_03_21%20SCOUT%20FAQ%20Sheet.pdf.

tool that allows responders to collaborate in a "white board" environment.[121] The software package was developed at the Lincoln Laboratories of the Massachusetts Institute of Technology in response to a DARPA challenge.[122] In partnership with Cal Fire, the web-based software is currently being tested for incident management of regional size. It is currently most commonly associated with managing wildfires in California but has also been tested for use on floods, special events, and hazardous materials incidents.[123] Designed to be used in the field, NICS is dependent on a wireless network infrastructure to function. In most cases, it utilizes the local commercial cellular network but Cal Fire has also developed proprietary portable wireless networking cells for use in wildlands where no commercial service is available. Features of NICS display include situational awareness information provided via map to include the location of single resources and their relativity to one another. NICS utilizes other benefits of broadband interfaces, including live continuous group chat rooms, video conferencing, and layered data feeds from commercial sources.[124] NICS software is currently managed by a not-for-profit agency called the NICS Users Group and will be offered to homeland security agencies at no cost.

NICS makes extensive use of GIS map features including the ability to track multiple incidents, various resources by type, and then layer data in a way that is contextually relevant to users. The symbols set in use by NICS is an amalgamation of symbols sourced from a variety of places, including Department of Transportation vehicle placards, ANSI symbols and a range of symbols they have developed internally.[125] It is important to note that none of the NICS symbols draw contextual data

[121] "Information Sharing Technology," accessed August 24, 2016, https://www.dhs.gov/science-and-technology/information-sharing-technology.

[122] DHS Science and Technology Directorate, *Next Generation Incident Command System* (Washington, DC: Department of Homeland Security, 2014), https://www.hsdl.org/?view&did=789279.

[123] Ibid.

[124] Gregory Hogan, "The Next-Generation Incident Command System (NICS)," paper presented at 2013 National Rural ITS Conference, St. Cloud, Minnesota, August 25–28, 2013, http://nationalruralits conference.org/downloads/Presentations13/Hogan__E1.pdf.

[125] Ibid.

from within the attribute table of the represented resource, and that resources are identified by various point symbols only, as depicted in Figure 1.

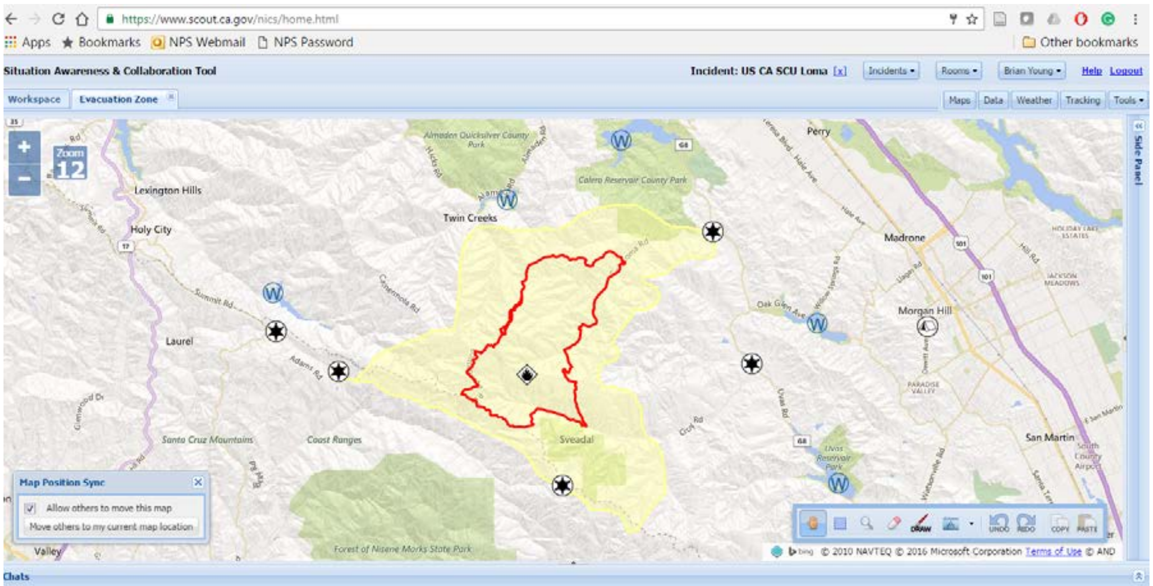

Figure 1. Next Generation Incident Command (SCOUT)[126]

In this case, even with a legend provided, users might discern the locations of the mapped resources but would be unable to determine features of those units without further inquiry into the attribute tables of each symbol.

2. Commercial Computer Aided-Dispatch Products

A range of vendors provides software for emergency responders nationally. Common to these software products is some form of GIS mapping incorporated to answer continuously the essential situational awareness questions of resource location, their relativity, and the best method to solve the problem at hand. These software solutions are chosen locally, and choices vary from one jurisdiction to the next, creating the patchwork of software systems that lead to the interoperability issues previously discussed. The depiction of mapped features on these systems follows a pattern similar to the NICS system; a combination of symbols drawn from various industries, in

[126] Source: Hogan, "The Next-Generation Incident Command System (NICS)."

conjunction with some nationally standardized symbols and some proprietary symbols. Within these various symbols, there may be multiple varied symbols for police cars, fire hydrants, hazards, and building features. Each system develops a visual language unique unto itself.

Tyler Technologies provides software solutions for police, fire, jail and emergency incident dispatching.[127] Their software is advertised to improve “the sharing of mission-critical information.”[128] Tyler’s Fire Mobile is advertised to improve situational awareness among responders via “high performance, easy to maintain maps.”[129] Figure 2 is a depiction of Tyler’s Fire Mobile™ application mapping.

Figure 2. Tyler Technologies Fire Mobile Mapping

Figure 2 depicts two mobile resources as points, with the underlying street network as lines. There is no applicable national standard for the depiction of a fire

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127 “Public Safety Software Systems & Solutions,” accessed August 24, 2016, http://www.tylertech.com/solutions-products/public-safety-solutions.

128 Ibid.

129 Tyler Technologies, *Fire and EMS Solutions - Integrated Software for Public Safety* (Plano, TX: Tyler Technologies, n.d.), http://www.tylertech.com/productsheets/NewWorld/New-World-Fire-EMS-Overview-Brochure.pdf.

engine or police car within these systems, so each vendor opts to display them differently. In this case, the symbol for either is a simple red vehicle, with a label differentiating between the two resource types. Please note that the Tyler product does not draw any contextual information from the attribute table of the features depicted, nor does it alter the symbols as the scale of the map changes, reducing the utility of the situational awareness data being conveyed. Figure 3 is a depiction of the same moment in time but at a wider scale of view. Without the application of cartographic conventions, cognitive compromises, and semiotics, it is very easy for mapping tools to become a blur of information with extremely limited utility.

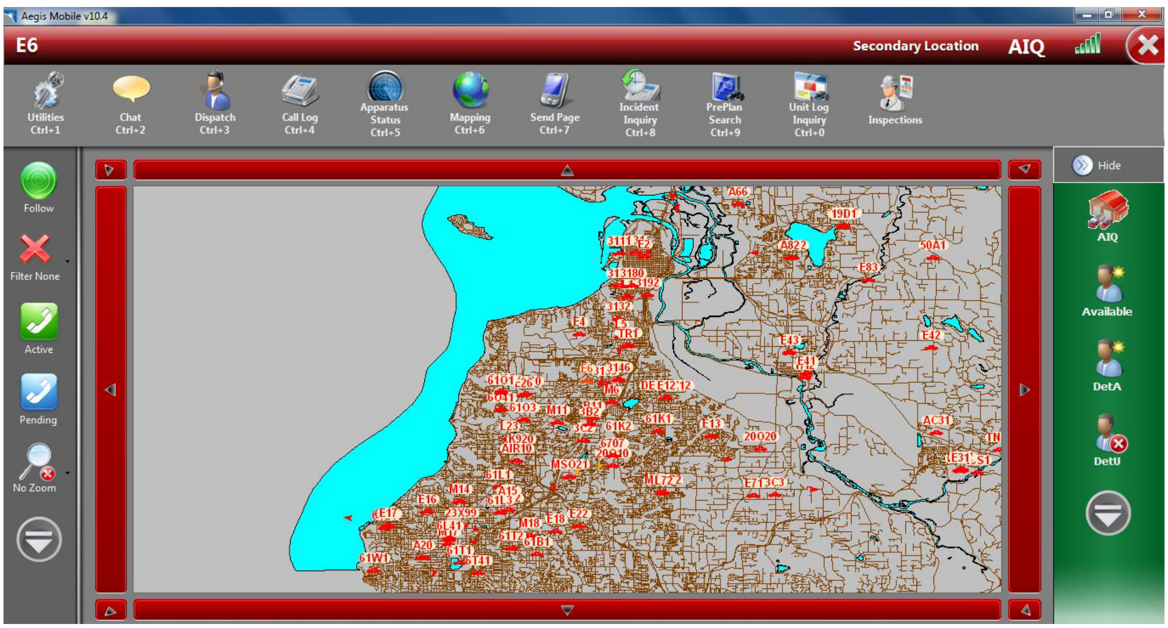

Figure 3. Tyler Technologies Fire Mobile Cartographic Conventions

TriTech Software Systems™ also offers a suite of computer-aided dispatch (CAD) products for sale. Similar to Tyler, they have chosen to integrate a GIS to help answer the "where" questions of situational awareness. TriTech has opted to partner with Google to embed Google Maps™ as their mapping tool rather than attempt to build their own.[130] There are several advantages to this strategy including the synergy between two

130 "Google Maps Interface," 2012, http://ledyardct.iqm2.com/Citizens/FileOpen.aspx?Type=4&ID=2293.

software systems, and the broad base of familiarity between consumers and Google products. Figure 4 depicts a fictional incident utilizing TriTech mapping software.

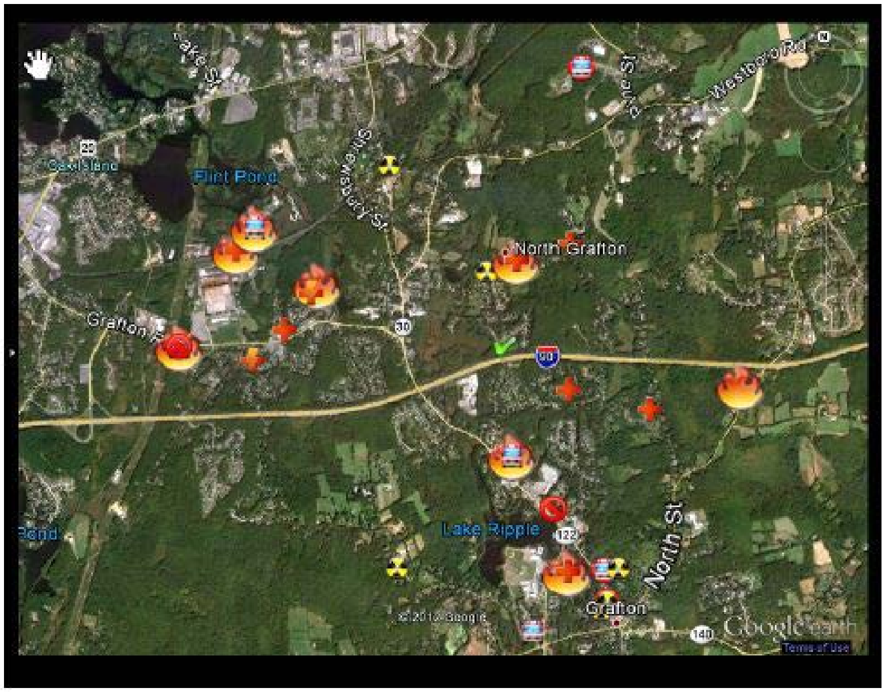

Figure 4. TriTech Mapping Solution Utilizing Google Maps[131]

Visible in the TriTech image is a layer of Google Earth™ satellite imagery with Google Streets™ overlaid. Much like NICS and Tyler software, the symbols representing various homeland security incidents and resources are unique to the system and visitors to the system would not necessarily be able to interpret the map easily. It is also important to note that homeland security features depicted in this example do not add context to each feature by drawing information from the feature's attribute table. The point symbols used as examples are able to provide location and relativity information and are differentiated by various shapes and colors, but little additional situational awareness can be gleaned from the depiction without further query of the attributes of each feature.

[131] Source: Ibid.

3. Google Maps for Government

Google provides its mapping tool to other software vendors as a subscription service for vendors creating application/program interfaces like TriTech. The company is also developing its own standalone map-based incident management tool for government.[132] Google boasts that its tools allow collaboration among silos and instant sharing of situational awareness data, much like the CAD software vendors. Figure 5 depicts a Google Maps for Government view of a flooding incident.

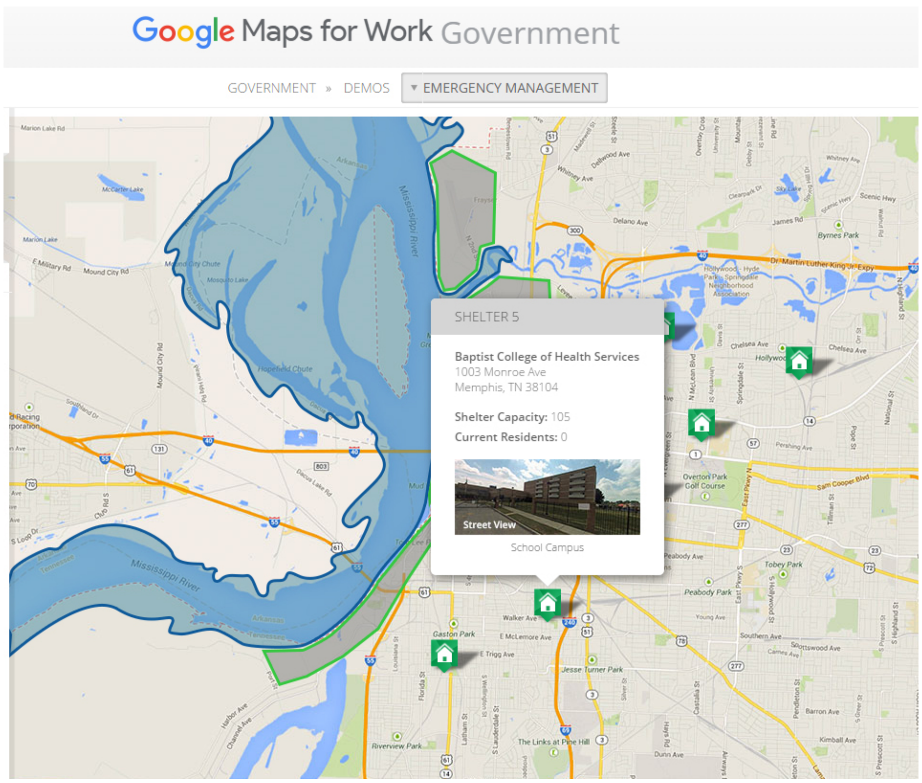

Figure 5. Google Maps for Government[133]

This depiction of a hypothetical flooding incident is utilizing a Google Street™ map with overlays of flooded areas and point symbols for emergency shelters. The Google product opens an abbreviated attribute table when the point is selected, offering

[132] "Mapping Solutions for Government: Google Maps for Government," accessed August 24, 2016, www.google.com/work/mapsearth/government/.

[133] Source: "Mapping Solutions for Government: Google Maps for Government."

contextually relevant information to responders, in this instance the maximum capacity and current population of the selected shelter. Please note the symbol for shelter is proprietary and the color chosen to represent its status is an example of using semiotics to provide context. Figure 6 depicts the addition of more contextual information by differentiating colors. This is a practical example of conveying context by varying the semiotics of the symbol based on data contained in the attribute table, allowing rapid dissemination of situational awareness about shelter locations, access, capacities, and current headcounts.

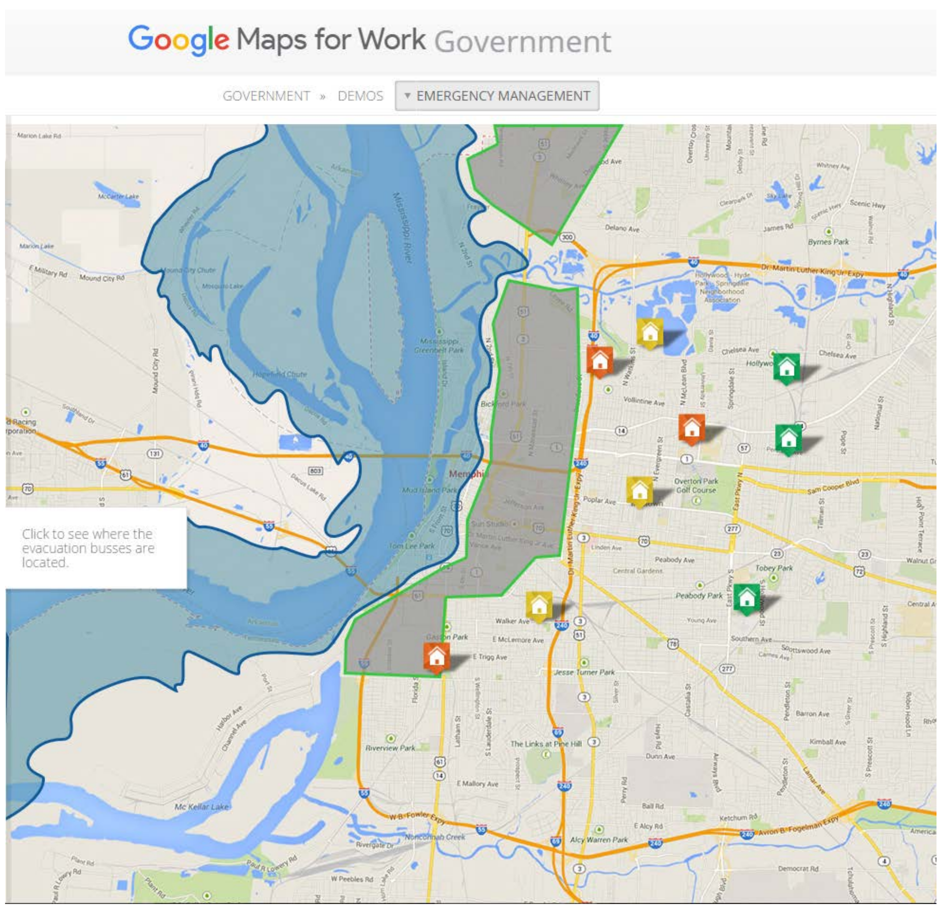

Figure 6. Google Maps for Government with Context Added[134]

134 Source: "Mapping Solutions for Government: Google Maps for Government."

D. GAPS IN CAPABILITIES

1. Pacific Northwest National Laboratory

The Pacific Northwest National Laboratory (PNNL) evaluated national emergency response capabilities in 2011, reviewing after-action incident reports, U.S. Government Accountability Office (GAO) reports, and interviews with subject matter experts from communities of various sizes.[135] As was frequently documented in the military literature for warfare, PNNL's first recognized responder need is for situational awareness, to create an environment for effective decision-making. PNNL differentiated between routine and large-scale operations but identified improved communications as a need for incidents of all scales. A particularly notable communications capability gap is the lack of readily deployable wireless infrastructure for use in large-scale events where domestic power and private wireless networks are overloaded or unavailable. States should have access to military-style deployable communications hardware similar to WIN-T.

PNNL identified divided gaps in situational awareness capabilities into three categories: dynamic situations, resource status, and geographic visualization.[136] Clearly, the three are interrelated and are simply another expression of the three fundamental situational awareness questions asked on the battlefield. The need for developing this information, storing it, and sharing it with counterparts as operational periods change is a key finding of PNNL research. PNNL interviewees felt collaboration between organizations prior to homeland security incidents was the best tool for combatting the challenges to creating a shared situational awareness between organizations; this collaboration creates relationships of trust and helps define a common incident language.[137] Developing a national common incident language for shared situational awareness is essential for homeland security. Examples used in this thesis depict

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[135] Pacific Northwest National Laboratory, *Gap Assessment in the Emergency Response Community* (Richland, WA: Pacific Northwest National Laboratory, 2011), http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19782.pdf.

[136] Ibid., v.

[137] Ibid., 3.2.

regionalized and inconsistent efforts to develop such a language. The need for a common visual language is clear.

2. ANSI Homeland Security Mapping Standard

The American National Standards Institute, in collaboration with the International Committee for Information Technology Standards (INCITS), has developed ANSI INCITS 415-2006 Homeland Security Mapping Standard (ANSI INCITS 415) in an effort to meet this need for a national common language for sharing situational awareness via map.[138] As virtually all the military and civilian situational awareness systems studied involve the extensive use of a GIS, these symbols were developed for digital mapping. The intended audience for this standard is the emergency management and first responder communities.[139]

The symbols contained within ANSI INCITS 415 have proven problematic and have experienced a poor adoption rate since their release in 2006.[140] The ANSI symbols set are all point symbols, intended to be applied to resources located at coordinates as well as applied in general to phenomena that may be distributed across a large area. No guidance is offered in the creation of polygons to describe wide-area events. The point symbols are divided into four categories: incidents by type, natural events, operations, and infrastructure.[141] There are three basic shapes for the four categories, and each symbol can be modified by a colored frame. No accommodation is provided for those items that may have geographic areas like incident boundaries or areas of operation. Figure 7 depicts the three basic shapes and the four possible frame modifiers.

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138 American National Standards Institute, *Homeland Security Mapping Standard—Point Symbology for Emergency Management* (Washington, DC: American National Standards Institute, 2006).

139 Ibid.

140 Robinson, MacEachren, and Roth, "Challenges for Map Symbol Standardization in Crisis Management."

141 Federal Geographic Data Committee (FGDC) Homeland Security Working Group, *Homeland Security Mapping Standard Point Symbology for Emergency Management* (ANSI INCITS 415-2006) (Washington, DC: Federal Emergency Management Agency, Department of Homeland Security, 2007).

Symbol Type	Symbol Frame	Symbol/Frame Color	Symbol Terms and Definitions
Incident (Damage/Operational No Levels)		*Purple*	*Incident (Incident: Damage/Operational)* – Not Applicable.
Natural Event (Damage/Operational No Levels)		*Black*	*Natural Event (Natural Event: Damage/Operational)* – Not Applicable.
Operation (Damage/Operational Level 1)		*Green*	*Operation (Operation: Damage/Operational)* - Fully operational/open.
Operation (Damage/Operational Level 2)		*Blue*	*Operation (Operation: Damage/Operational)* - Operational, but filled to capacity or otherwise closed.
Operation (Damage/Operational Level 3)		*Orange*	*Operation (Operation: Damage/Operational)* - Operational, but partially damaged or partially incapacitated.
Operation (Damage/Operational Level 4)		*Red*	*Operation (Operation: Damage/Operational)* - Destroyed or Totally incapacitated.
Infrastructure (Damage/Operational Level 1)		*Green*	*Infrastructure (Infrastructure: Damage/Operational)* - Fully operational/open.
Infrastructure (Damage/Operational Level 2)		*Blue*	*Infrastructure (Infrastructure: Damage/Operational)* - Operational, but filled to capacity or otherwise closed.
Infrastructure (Damage/Operational Level 3)		*Orange*	*Infrastructure (Infrastructure: Damage/Operational)* - Operational, but partially damaged or partially incapacitated.
Infrastructure (Damage/Operational Level 4)		*Red*	*Infrastructure (Infrastructure: Damage/Operational)* - Destroyed or Totally incapacitated.

Figure 7. ANSI INCITS 415-2006 Point Symbology Schema[142]

Figure 8 depicts an example of an operation point symbol for an ambulance, and the four frames that can be used to modify the symbol describing its state of functionality.

[142] Source: Federal Geographic Data Committee (FGDC) Homeland Security Working Group, *Homeland Security Mapping Standard Point Symbology for Emergency Management*, 6.

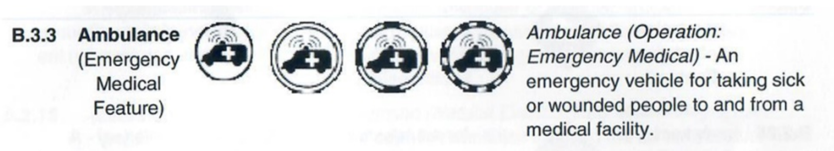

Figure 8. ANSI INCITS 425-2006 Point Symbol Variations[143]

Figures 7 and 8 demonstrate significant shortcomings in the standard. First is the black-and-white guidance document itself, with a textual description of color. In a full-color world, the guidance document should depict the colors intended for use rather than describe them. Division of the symbols set into four categories is useful, as it allows for sorting and filtering by data type; however, the symbols set opens up the opportunity for confusion by using only three symbols to depict four categories. Additionally, "incidents" typically occupy one or more geographies with physical area, rather than points. Finally, it is critical to note that the point symbols for resources, as depicted in Figure 8, do not draw information from the attributes of the resource being featured, and thus, do not create much useful context for the reader.

Robinson, McEachren, and Roth have studied the low organizational adoption rates for ANSI INCITS 415 by interviewing subject matter experts (SMEs) from a variety of homeland security agencies and disciplines. Their study concluded that most SMEs were familiar with the standard but typically only utilized a small number of the symbols and often with custom local modifications.[144] SME comments regarding the standard symbols suggest they are not organized in a useful manner, are too complicated, or are not relevant to their individual areas of operation.[145] In summary, the ANSI INCITS 415 symbols fail to provide a common, interoperable language for use in emergency operation. The failure is not a result of poor symbols selection, but rather the lack of applied semiotic principles and the lack of useful attribute information to assist in the creation of context.

[143] Source: Federal Geographic Data Committee (FGDC) Homeland Security Working Group, *Homeland Security Mapping Standard Point Symbology for Emergency Management*, 16.

[144] Robinson, MacEachren, and Roth, "Challenges for Map Symbol Standardization in Crisis Management."

[145] Ibid., 4.

IV. ANALYSIS OF DEPARTMENT OF DEFENSE SITUATIONAL AWARENESS TOOLS AND THEIR APPLICABILITY TO CIVILIAN USE

A. COMPARISON OF DOD AND DHS ACTIVITIES AND INFORMATION NEEDS

It is impossible to ignore the similarities between the situational awareness needs of the various branches of the DOD and homeland security responders. Both face similarly high stakes: American lives hang in the balance, there can be vast social and economic impacts as a result of actions taken, and organization of resources must occur across a broad area under the most challenging of circumstances. Carl von Clausewitz made the observation that "everything in war is simple, but the simplest thing is difficult."[146] This simple conception about warfare is equally true of homeland security incidents.

Armed forces in action manage violence in an effort to impose American will on enemies. Warfighters face many challenges in this endeavor and they are best described in the Marine Corps doctrinal book *Warfighting*. The Marines state that the clash of wills on the battlefield inherently creates friction, which can be created by many physical things including enemy action, weather, terrain, or simply chance.[147] However, friction can also be caused by human miscalculation and confusion resulting from poorly defined goals, miscommunication, complex plans, or unclear commands. The Marine Corps feels friction is a result of warfare being a human endeavor and will, therefore, always be present on the battlefield. It is their intention to manage friction as a matter of course and work to be an effective fighting force despite the presence of friction in every action they take.[148] The confusion resulting from frictional forces is often described as "the fog of war," a term often ascribed to von Clausewitz.[149]

[146] U.S. Marine Corps Staff, *Warfighting*, 1.

[147] Ibid., 2.

[148] Ibid., 3.

[149] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 7.

American responders historically have not faced organized, heavily armed enemies like those faced by American soldiers. Law enforcement has traditionally involved single perpetrators or organized crime for profit within the homeland. Firefighters have faced a mindless enemy intent on destroying lives and property, but not in an intentional and willful way. Emergency medical services personnel are trained to manage medical crises and traumatic injuries associated with human health and activities of daily living. State and federal response assets have been organized around the management of natural disasters and other unintentional events that cannot be managed at the local level. Unfortunately, all these roles are changing as America's enemies diversify and find new ways to attack the homeland. The scope and threats of terrorism were redefined on September 11, 2001, and continue to evolve. Currently, homeland security responders still face their traditional foes but have been forced to adapt to the evolution of terrorism and the militarization of criminal behavior. Police officers face military-grade weapons and tactics and must learn to respond in kind.[150] Recent attacks in Dallas, Texas and Paris, France illustrate the evolving roles of firefighters and emergency medical services personnel who must learn to manage large volumes of afflicted patients across incident sites that are large and geographically diverse while under the threat of ongoing violence. America's responders increasingly face the same friction-driven fog as American soldiers on the battlefield. Examining how armed forces manage this fog is a necessary endeavor for responders.

The fog caused by friction must be overcome with a variety of tools. Driesslein suggests that network-centric warfare is an important and developing tool for management of confusion through better information sharing.[151] In 2001, the DOD identified network-centric warfare as a key tool for battlefield awareness in a report to Congress and described four tenets of the network-centric battlespace:[152]

[150] Geron, "Reflections by a Dallas Police Officer."

[151] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 6.

[152] U.S. Department of Defense, "Network Centric Warfare Department of Defense Report to Congress."

- A robustly networked force improves information sharing.
- Information sharing and collaboration enhance the quality of information and shared situational awareness.
- Shared situational awareness enables self-synchronization.
- These, in turn, dramatically increase mission effectiveness.[153]

These tenets describe the value of networked data on the American battlefield, but the similarities between military information needs and those of civilian responders cannot be overstated, forcing civilian responders to consider the need for defining a network-centric response. Development of such a response is well underway as described in Chapter III. For the purposes of this thesis, we will consider the four tenets of network-centric warfare as being perfectly applicable to the homeland security response communities.

Warfighting describes other attributes of war that translate to civilian response. "Uncertainty" is described as pervasive and applies to almost every aspect of combat from weather to enemy intentions.[154] While a portion of uncertainty must always be governed by chance, the effects of uncertainty can be reduced by applying risk management principles.[155] This is true on the battlefield and in the homeland security workspace. Soldiers may develop flexibility in mission planning and train extensively on strategy and tactics so their responses to uncertainty become predictable. These same risk management strategies are applied by homeland security responders to reduce uncertainty during incidents. Firefighters and police officers train extensively so their actions become predictable during uncertainty. Responders pre-plan their responses to known threats within their communities to reduce risk further and eliminate uncertainty.

Fluidity and disorder are two more attributes of warfare[156] that also appear during homeland security incidents. Hudson and Rzasa describe a human cognitive limit to the

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[153] U.S. Department of Defense, "Network Centric Warfare Department of Defense Report to Congress."

[154] U.S. Marine Corps Staff, *Warfighting*, 4.

[155] Ibid., 5.

[156] Ibid., 6.

number of variables an individual can assimilate, with the deterioration of situational awareness occurring when that limit is reached.[157] The fluidity and disorder of information on the battlefield create a “saturated data pool that is unorganized, irrelevant, and redundant”[158] resulting in confusion among commanders. This fluidity and disorder are reduced through the use of a visual interface that can be used by commanders to categorize and sort information into useful groupings.[159] Driesslein agrees and suggests the solution lies in a networked information system deployed across the battlespace, which reduces confusion and improves resource utilization and effectiveness.[160] Homeland security responders face the same fluidity as events unfold and evolve in the homeland, often confronting the same disorder described by Major Guron during the July 2016 shootings of his officers. Homeland security responders would benefit equally from Driesslein’s system of networked relevant information during times of fluidity and disorder.

Complexity and human factors are elements of the modern warfighting battlespace.[161] The two are closely interrelated and presented frequently on the battlefield as war is a human endeavor. All the complexities of human morality can be found in the theater of war, as well as the effects of human exhaustion, willpower, courage, and fear.[162] No amount of technical application can eliminate the complex presence of human factors on the battlefield, but Hudson and Rzasa contend that supported human decision making is the only effective response to this complexity. Support is best offered by an information system that delivers appropriate data within a useful timeframe.[163] This same logic can be applied to homeland security incidents, as responders face the human factors

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[157] Hudson and Rzasa, “Knowledge Visualizations: A Tool to Achieve Optimized Operational Decision Making and Data Integration.”

[158] Ibid., 1.

[159] Ibid., 2.

[160] Driesslein, “Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations,” 8.

[161] U.S. Marine Corps Staff, *Warfighting*, 8.

[162] Ibid.

[163] Hudson and Rzasa, “Knowledge Visualizations: A Tool to Achieve Optimized Operational Decision Making and Data Integration,” 11.

created by criminals, terrorists, and everyday citizens. The layers of human complexity within the homeland include willful plotting of violence to shoddy construction techniques contributing to fire loss. Management of this complexity within the homeland is best addressed by human decision making supported by an information system that organizes and filters relevant information in a timely manner.

Violence and danger are ever-present on the battlefield.[164] Warfare is the practical application of force to cause the submission of an enemy and is inherently dangerous.[165] Violence and danger are also ever-present in the homeland, with perhaps the principle difference between the purposes of the DOD and the DHS being the intentional use of force prevalent in warfare being absent in homeland security. That aside, danger is ever-present in both arenas. The Marine Corps suggests the study of human fear as part of the doctrine for Marine officers.[166] Through the study of fear, they can discover the means to manage and reduce it, thereby improving their performance and effectiveness. In the homeland, live fire training exercises and developing strong leadership skills among officers are applied in the name of fear reduction to improve homeland security response. While the missions are starkly different, the management of fear and the unknown through preparation and training are essential similarities between the DOD and the DHS. It stands to reason that those tools effectively applied in one arena can and should be considered for application in the other. A symbiotic relationship exists, with the DOD having an advantage in the breadth of experience and funding, thus making it a valuable proving ground for methods in matters of homeland security.

B. NETWORKING THE BATTLESPACE FOR SITUATIONAL AWARENESS

American warfighters are finding their foes equipped with mobile information networks in the form of commercial cellular towers and handheld smartphones. This seemingly innocuous reality is providing enemies with better real-time situational

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[164] U.S. Marine Corps Staff, *Warfighting*, 8.

[165] Ibid., 9.

[166] Ibid.

awareness, allowing exploitation of American information exchange weaknesses.[167] American armed forces deploy with arguably the best training and equipment in the history of man, yet in Afghanistan, the Taliban was able to outmaneuver U.S. forces effectively via the instant deployment of information from their leadership sequestered in Pakistan to their field commanders via smartphones.[168] American fighting forces were faced with an enemy that rarely gathered in great strength, yet was able to share situational awareness information and manage their command and control using networked wireless communications.[169] It became clear to America's commander in theater, General Stanley McChrystal, that despite America's superior fighting forces, they were facing information superiority, and developing a military information network was the only solution that would deliver the "knowledge, speed, precision, and unity of effort" necessary to defeat a networked enemy.[170]

It was on the battlefields of Afghanistan that the U.S. military first attempted to connect every warfighting element. Regardless of role or geographic distribution, an attempt was made to form a comprehensive, wireless information network capable of managing not just the volume of wartime data, but also the effective dissemination of the right data to the right people at the right time.[171] This military effort to network information effectively is still ongoing, but lessons about the value of network-centric warfare have emerged: Networks decentralize decision making, allowing speedier reactions to evolving conditions and eliminating information overload from a central commander. Networks also remove institutional boundaries, allowing cooperative but varying cultures to mesh, allowing more effective selection and utilization of resources. Finally, and perhaps most importantly, a network was found to facilitate the emergence

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[167] Erwin, "U.S. Troops Loaded with Technology, But Can't Harness the Power of the Network– Blog."

[168] Stanley A. McChrystal, "It Takes a Network," Foreign Policy, February 21, 2011, https://foreignpolicy.com/2011/02/21/it-takes-a-network/.

[169] Ibid.

[170] Ibid.

[171] Ibid.

of competence in decision making, regardless of rank.[172] All these features are equally desirable during complex homeland security events involving multiple agencies that are geographically diverse and arrive with their own institutional context. The progression of network-centric response should be similarly developed using the same strategies as those of network-centric warfare.

The traditional network model in use by the military, as well as most corporate and private networks, is the client/server network.[173] A client/server relationship can be found within one computer between related software programs, but more importantly, the client/server relationship is best depicted by networked computers.[174] In a client/server model, a central program runs on the more powerful server computer and its resources are accessed by an authorized client computer equipped with compatible client software. Data is exchanged in both directions between the client and the server, depending on the purpose of the software. Figure 9 depicts a traditional client/server network.

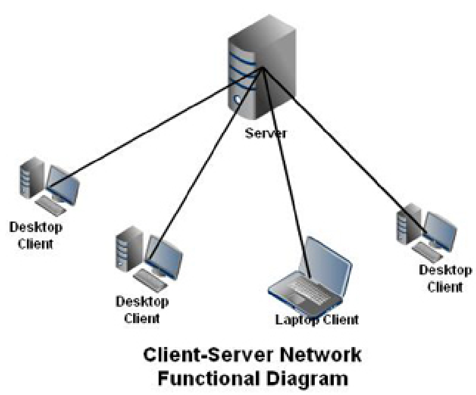

Figure 9. A Client/Server Network

The most common application of networked client/server networks is the internet, which utilizes a defined communication protocol for communication between diverse

[172] Ibid.

[173] "What Is Client/Server (Client/server Model, Client/server Architecture)?" accessed August 15, 2016, http://searchnetworking.techtarget.com/definition/client-server.

[174] Ibid.

clients and servers known as transfer control protocol/internet protocol (TCP/IP).[175] According to the Army Vice Chief of Staff, General Peter Chiarelli, developing a modern information network is the U.S. Army's "highest modernization priority."[176] To that end, several field deployable systems have been developed utilizing commercial and proprietary technology whose purpose is to create a wireless client/server network within a theater of conflict.[177]

C. THE WARFIGHTER INFORMATION NETWORK—TACTICAL

The need for continuous networked communication of data during DOD operations has resulted in the development of the Warfighter Information Network – Tactical (WIN-T). WIN-T assets include all the features of a commercial client-server network but are built to military specification for ruggedness and portability. Their purpose is to extend an information network from fixed regional hubs to field units via typical network hardware like Ethernet modems and client computers using a defensible array of vehicle-borne network hubs, network nodes, and satellite terminals.[178] WIN-T allows the interconnection of a variety of other information-sharing technologies on the battlefield and is interdependent on other systems including battle command servers, the enhanced position location and reporting system, and a range of vehicle-borne hardware for deployment.[179] The development of the modern U.S. Army network referenced as a top priority by General Chiarelli is developing as the incremental steps of the WIN-T wireless communication system. The continuous availability of a wireless data information network is the backbone upon which situational awareness software solutions are developed. WIN-T is an over-land example of the hardened infrastructure required to create the pathways by which client/server applications communicate data and is

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175 Chris Peters, "Networking 101: Concepts and Definitions," WebJunction, March 21, 2012, https:// www.webjunction.org/documents/webjunction/Networking_101_Concepts_and_Definitions.html. WebJunction.

176 Erwin, "U.S. Troops Loaded with Technology, But Can't Harness the Power of the Network– Blog."

177 United States Army, *Weapon Systems 2012 America's Army: The Strength of the Nation*, 318.

178 Ibid.

179 Ibid.

foundational to network-centric warfare. The military utilizes a range of other networks for communication at sea or in the air. To realize the known benefits of a network to homeland security response, this same communications backbone must exist at all times for the development of network-centric response capabilities. Efforts are underway but do not currently exist in the homeland.

D. PUBLISH/SUBSCRIBE NETWORK MODEL

While network-centric warfare is currently built on client/server infrastructure, it is worthy to note other models are being studied by the DOD that may eliminate several of the known weaknesses of a client/server network. Weaknesses of client/server networks include overreliance on servers as hubs, which exposes the network to collapse if a hub is eliminated. As the client/server network becomes mobile, it is increasingly susceptible to the inherent difficulties of terrain, which interferes with wireless transmission via obstacles, distance, and unplanned concentration of nodes.[180]

In a publish/subscribe network there is no central server; each mobile client is a publisher of and a subscriber to data relevant to the network.[181] Each client "subscribes" to a particular topic that is stored in a series of tables on an overlaying network of information "brokers." For all clients wishing to report on (publish) a topic, and all those interested in the updates of those topics (subscribers), each client remains up-to-date with the other, with no central oversight from a server.[182] The simplest description of the benefit of such architecture is the network's resilience in the mobile environment; with no dependence on servers, nodes may disappear and/or reappear and with no net effect on the information available at any given time. In layman's terms, the network can lose clients with no functional loss of information. Driesslein describes the military application of a publish/subscribe network in his research on man-portable clients to allow networking of individual soldiers. His research focuses on the benefits of eliminating the addressing of routed network data, which is lost when the destination

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[180] Gianpaolo Cugola, Amy L. Murphy, and Gian Pietro Picco, *Content-Based Publish-Subscribe in a Mobile Environment*, n.d.), https://es-static.fbk.eu/people/murphy/Papers/mobMwBook.pdf.

[181] Ibid., 3.

[182] Ibid.

address has been removed from the network. Publish/subscribe allows for the loss of individual soldiers while retaining the entire information knowledge base of the network.[183]

Homeland security responders may not always face armed enemies intent on destroying their information network, but currently, the United States is not covered by a unifying wireless network infrastructure. The need for situational awareness information to reside within a resilient network is similar to the needs of the DOD. Homeland security networked clients will pass through terrain that interferes with reception, or travel distances that take them out of range of the network or concentrate in narrow areas resulting in poor network performance. All these parallel issues are improved in a publish/subscribe network that allows for intermittent connection of mobile client nodes with no overall loss of network information.

E. LINK 16

Link 16 is a tool in use by the United States Navy and Air Forces. Described as a "highly structured network" whose purpose is to share mission-related data in real time among air and sea assets.[184] This proprietary system utilizes line of sight wireless communication between encoded Link 16 consoles to share live information across the network.[185] Link 16 might be better described as a network of networks, as it allows administrators to divide client consoles into up to 127 separate networks.[186] This ability allows smaller workgroups, for example, a flight of fighter aircraft, to utilize a theater-wide Link 16 network but to maintain their flight-specific situational awareness as their data is separated from other users of the same network. This improves situational awareness by reducing information overload and delivering mission-specific data within a network managing much more information. Link 16 can sort information into layers

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[183] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 37.

[184] Hura et al., *Interoperability: A Continuing Challenge in Coalition Air Operations*, 108.

[185] Ibid.

[186] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 15.

based on the assigned attributes of the users, which provides much needed informational context for situational awareness. Since Link 16 hardware is extremely proprietary, limited to line-of-sight, and has a physical limit to the number of users, it is a poor fit for domestic homeland security applications, but elements of its capabilities will be shown as critical to the success of network-centric response.

F. RESOURCE MOVEMENT TRACKING SYSTEMS

1. Blue Force Tracking

In the 1990s, the digitization of the U.S. Army included moving the time and battle tested methods of analog resource tracking from the command post map table to the computer. The need for information superiority on the three most important battlefield questions has determined the fates of entire armies and nations: "Where am I?" "Where are my forces and other friendly forces?" "Where is the enemy and what is the best route to attack him?"[187] Blue Force tracking is the first term ascribed to that digital effort, a software system run on military networks that reported the locations of friendly forces and known enemy forces. The arrival of the global positioning system (GPS) made the instant digitization of location data possible and opened an array of new capabilities for tracking resources.

Early GPS answered the "Where am I?" but additional technology was needed to answer the remaining two questions. Understanding your location in relation to other resources and various objectives is essential information for warfighters and responders. Location is valuable to situational awareness as an individual but provides no awareness beyond self. The location of friendly and foe forces, directions of travel, and progress toward common objectives modifies individual knowledge by creating situational context. Contextual data is subtly different from single situational data points in that it colors the situational data by identifying relationships. The depiction of the relationships between the features, movements, and attributes of various resources is absolutely essential to creating battlefield situational awareness. Blue Force tracking was a first

[187] Dunn, *Blue Force Tracking—The Afghanistan and Iraq Experience and Its Implications for the U.S. Army*.

attempt not only to relay single unit data but to depict the contextual relationships between them and transmit them via networked clients.

Interestingly, the name of the software system itself unintentionally identifies a semiotic principle important to relaying situational awareness. “Blue Force” is a semiotic contextual concept in use to help differentiate friend from foe in a digital environment. The use of colors to differentiate between forces predates academic writing on the subject. Soldiers in the Napoleonic era wore red (French) or blue (British) uniforms to help distinguish between them during the fog of war. The application of color to a resource takes advantage of the human ability to communicate with a visual language. On a Napoleonic battlefield, an officer could observe a cannon emplacement and use the color of the uniforms to identify its allegiance. The same principle has been digitized by Blue Force tracking: A quick glance at the various forces depicted digitally uses color variation to differentiate between friendly, allied, unknown, and aggressor forces. Figure 10 depicts friendly military assets tracked as a “Blue Force.”

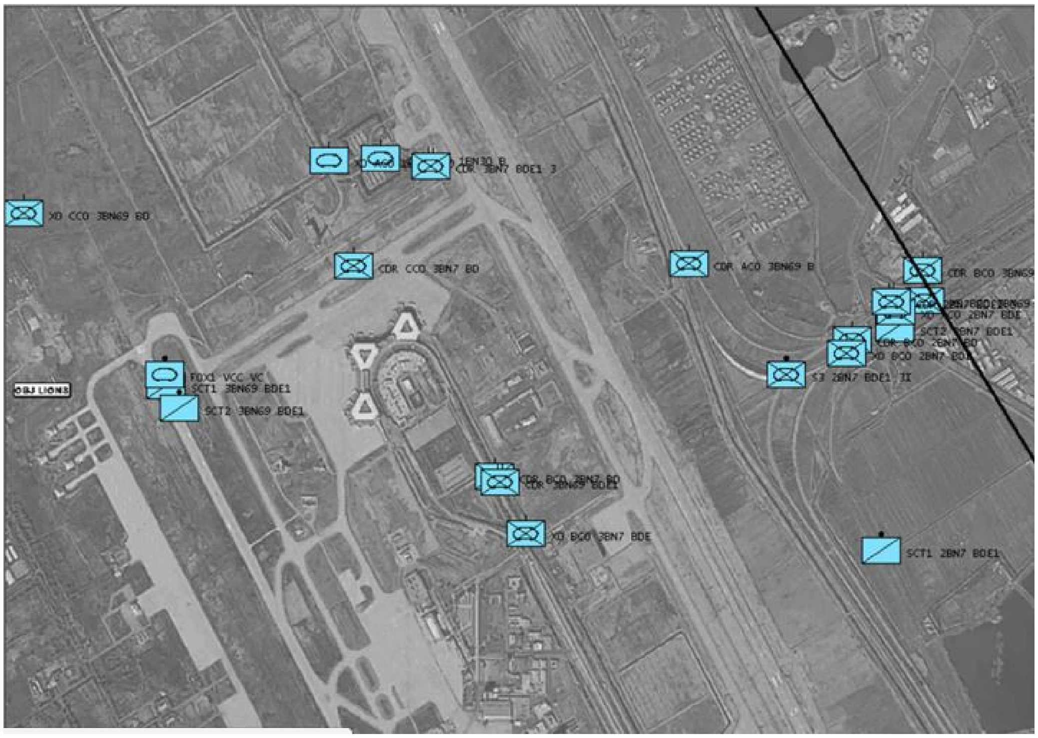

Figure 10. Blue Force Tracker[188]

The digitization of the war room map in conjunction with global positioning allows for the display of traditional battlefield formations but also an entire array of support forces. Troop maneuvering, directing fields of fire, and avoiding friendly-fire casualties requires the software system to identify friendly forces effectively, quickly, and consistently on the battlefield.[189] Coloring all friendly forces blue is at once an incredibly simple concept, but is also an example of the power of semiotics in situational awareness. Tracking resources of all types during homeland security incidents will require the same elegant simplicity.

2. Force XXI Battle Command—Brigade and Below

The evolution of blue force tracking in the Army has arrived at a situational awareness system known as Force XXI Battle Command—Brigade and Below (FBCB2).

[188] Source: "BFT2 Baghdad Airport," November 12, 2015, http://usa-satcom.com/wp-content/uploads/2014/11/FBCB2_of_Baghdad_International_Airport.png.

[189] Ibid.

FBCB2 is the current digital command and control system in use by the U.S. Army.[190] FBCB2 terminals have been added to all mounted units of several Army brigades to provide situational awareness on the battlefield. FBCB2 reports on all friendly force locations as well as all known enemy force locations via graphics overlaid on a digital map.[191] Figure 11 depicts a FBCB2 depiction of blue and red forces.

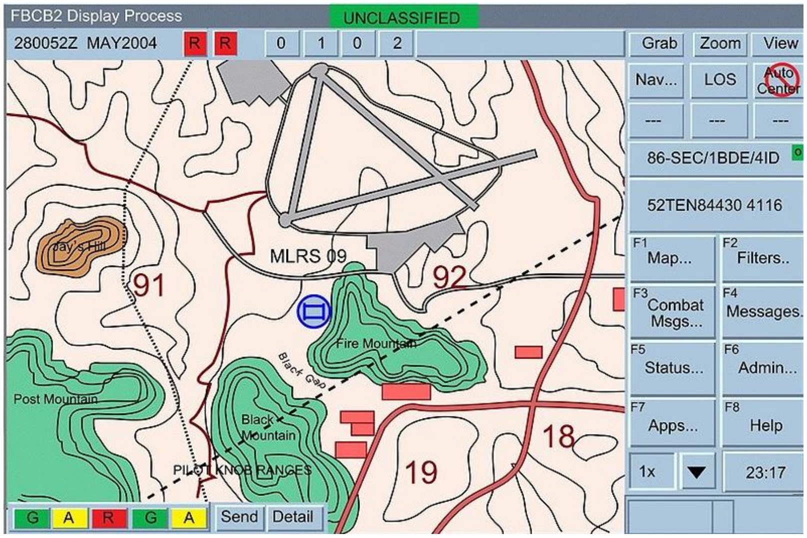

Figure 11. Force XXI Battle Command Brigade and Below[192]

FBCB2 operates on the tactical internet created by the WIN-T network and depicts situational awareness data, as well as contextual relationships between resources. FBCB2 is similar in structure to Blue Force Tracker and due to the size of technology requirements, it does not deploy on anything smaller than a motorized vehicle.[193] This limitation makes tracking resources smaller than vehicles (like infantry units or single soldiers) impossible with FBCB2.[194] Driesslein suggests the possibility of integration

[190] United States Army, *Weapon Systems 2012 America's Army: The Strength of the Nation*, 108.

[191] Ibid.

[192] Source: "File:FBCB2 CreateDevice OperationsScreen.jpg," last modified June 17, 2014, https://commons.wikimedia.org/wiki/File:FBCB2_CreateDevice_OperationsScreen.jpg.

[193] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 19.

[194] Ibid.

between FBCB2 systems and Link 16 systems, dramatically expanding the scope of battlespace situational awareness and command and control functions to land, sea, and air in theater. However, neither of these systems tracks the resources below the resolution of vehicles, leaving the unmounted soldier still unaccounted for in any expanded FBCB2/Link 16 network.[195] Homeland security responders do not yet enjoy the benefit of tracking all resources at the vehicle level.

G. MAPPING AT THE HEART OF MILITARY SITUATIONAL AWARENESS

Whether it be ground asset tracking with FBCB2 or sea and air assets with Link 16, at the heart of each system lies a mapping tool. The data collected in each of these systems first and fore mostly attempts to answer that basic situational awareness question: where am I? A map is the best tool to answer that question.[196] Maps have served that purpose in military operations long before the development of digital information exchange. Mapping dates to at least 5,000 B.C. with early examples found carved in stone.[197] Mapping has long been a military function, including mapping of the world and oceans as civilizations spread across the globe. The modern American DOD relies heavily on the mapping of land, sea, air, and even space for the movement of resources and to provide continuously updated situational awareness data to users of the various systems previously described.

The U.S. Army wants its maps to provide extensive information for its users. To that end, it has developed publication ADRP 1-02, which is a 350-page guide to common mapping terms and military symbols. The document incorporates and accompanies six different allied international reference documents on the same subject in an effort to establish a common contextual mapping language among all allied warfighters.[198] ADRP

[195] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations," 19.

[196] Meehan, "Access, Awareness, and Analysis—All in One Location Platform."

[197] "Fundamentals of Mapping," accessed August 17, 2016, http://www.icsm.gov.au/mapping/history.html.

[198] United States Army, *ADRP 1-02 Terms and Military Symbols* (Arlington, VA: United States Army, 2015), http://armypubs.army.mil/doctrine/DR_pubs/dr_a/pdf/adrp1_02.pdf.

1-02 provides guidance on the creation of basic Army symbols, separated by resource type as depicted in Figure 12.

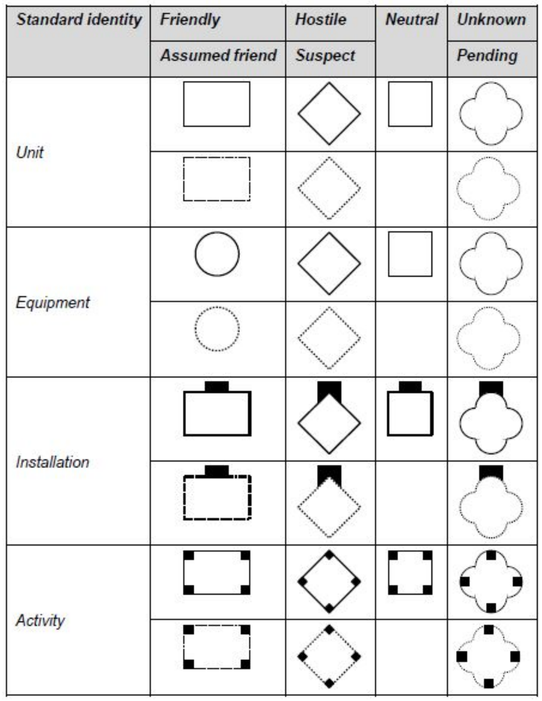

Figure 12. ADRP 1-02 Military Symbols Schema[199]

It is not necessary to be a trained military intelligence officer to recognize some of the important concepts of symbols in use by the Army. Army symbols, in this case, are separated into layers: units, equipment, installations, and activities depicted by unique shapes. They are further subdivided into groups: friendly, hostile, neutral, and unknowns. With minimal training, a layperson could learn to make these distinctions at a glance. When coupled with the power of a map, these symbols answer the critical questions about unit location, relationships, activities, and intentions. Figure 13 is an example of using semiotic principles to plot current and anticipated future tenses of circumstances to military symbols.

[199] Source: United States Army, *ADRP 1-02 Terms and Military Symbols*, 3–2.

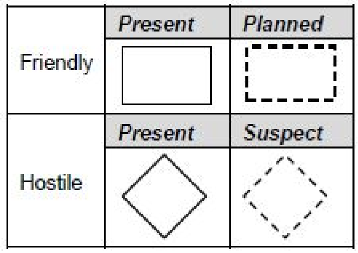

Figure 13. Additional Context within ADRP 1-02[200]

With a simple semiotic variation of these black and white line symbols, the Army is able to create situational awareness about current and anticipated resource locations and activities. It is also able to modify its basic symbols with “amplifiers” to add additional contextual information to each symbol. Figure 14 is a reference chart for the standard placement of amplifiers on U.S. Army symbols.

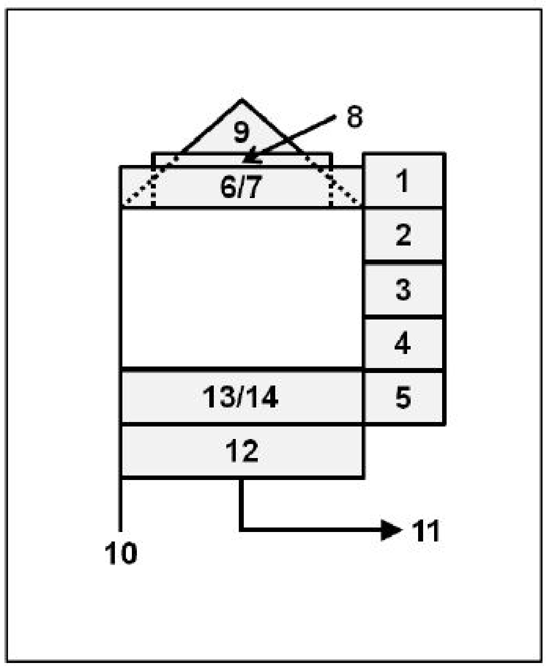

Figure 14. ADRP 1-02 Symbol Amplifier Schema[201]

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[200] Source: United States Army, *ADRP 1-02 Terms and Military Symbols*, 3–3.

[201] Source: Ibid., 3–4.

The various numbered locations represent standardized locations for the placement of amplifiers that add additional context to each symbol. These amplifiers include items like the country of origin, task force assignments, current activity, and other items drawn from the attributes of the unit itself.[202]

This is a critical point and warrants repeating. Army symbols draw data from the attributes of the resource and are used to amplify (improve) the symbol's ability to provide situational awareness by adding context to the symbol itself. Marking and mapping locations of resources and easily interpreting the context of those resources are highly desirable capabilities for homeland security operations. While the missions are different, the challenges faced by warfighters and homeland security responders are interrelated. The DOD has found the mobile data network to be its top development priority for communicating situational awareness between allied resources. Its networked situational awareness tools are built on map-based mediums, using color and shape to communicate visually, with symbols that can be modified (or amplified) with contextual data to improve warfighters' understanding of not only their location and actions, but the location and actions of friendly and aggressor assets within their chosen field of view. A common visual language for communicating this awareness must be defined for homeland security responders.

[202] United States Army, *ADRP 1-02 Terms and Military Symbols*, 3–6.

V. SEMIOTIC PRINCIPLES FOR COMMUNICATING SITUATIONAL AWARENESS IN THE HOMELAND

A. THE SCIENCE OF VISUAL COMMUNICATION

Semiotics has been described as the intersection of the "world of thought and the world of physical objects."[203] Deely suggests the "whole of human experience, without exception, is an interpretive structure mediated and sustained by signs."[204] Visual communication combines the utility of verbal language with the multi-dimensionality of graphic representation.[205] This compounding of communication, known as metalanguage, allows the transfer of cognitive information more effectively and at greater speed.[206] Long before the science of semiotics was studied or understood, man has been using graphic representations to define and communicate the reality around him. The metalanguage afforded by visual communication allows more effective communication of situational awareness, whether it is on the battlefield or in the homeland.

A map lies at the heart of a successful response.[207] By definition, a map is a graphic representation of the real world, which can be rendered to relay many layers of information about the same physical space.[208] Semiotic principles can be used to differentiate and convey geographic information better than verbal exchange. Verbally exchanged information is fraught with ambiguity and semantic interpretation that causes confusion during homeland security incidents.[209] Visual communication can be pre-planned and a homeland security language can be built around the concept of objectivity.

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[203] John Deely, *Advances in Semiotics* (Bloomington: IN: University Press, 1990), 7.

[204] Ibid., 5.

[205] Saint-Martin, *Semiotics of Visual Language*, xiii.

[206] Ibid.

[207] "Successful Response Starts with a Map: Improving Geospatial Support for Disaster Management," accessed October 12, 2015, http://www.nap.edu/catalog/11793/successful-response-starts-with-a-map-improving-geospatial-support-for.

[208] Longley et al., *Geographic Information Systems and Science*.

[209] Siska Fitrianie and Leon J. M. Rothkrantz, "A Visual Communication Language for Crisis Management," *International Journal of Intelligent Control and Systems* 12, no. 2 (June 2007): 208–16.

Visual conventions can be designed to be transparent and factual, reducing the confusing nuance of verbal communication.[210]

B. PERTINENT PRINCIPLES OF SEMIOLOGY

Communicating via a visual language is more effective than verbal language, allowing for compounded layers of information to be conveyed simultaneously as a metalanguage.[211] Human perception of colors, shapes, and textures combined with points, lines, and planes can produce an "endless variety" of communicable units that far outstrips the possibilities of the spoken word both in terms of variety and data exchange rate.[212] The colorme has been described as the most fundamental visual object; several properties unique to the colorme are relevant to visual communication in homeland security.

(1) Color

Chemists have identified over 60,000 varieties and shades of discernably different colors, and in general, humans are adept at distinguishing approximately 10,000 of them visually.[213] At first glance, this suggests an almost endless palette for symbolizing information, but man is only able verbally to convey approximately 12 basic color groups, making many of the various shades impractical to oral description.[214] As verbal communication will always play a role in homeland security incidents, the ability to verbally differentiate between elements of a visual language is desirable. Whysel suggests that the contrast between two colors may have more value than varying shades when communicating symbolized mapped information.[215] Contrasting colors improves their visibility when overlaid on a variety of backgrounds, making high contrast a desirable quality for the visual language of homeland security. Interestingly, no literature

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[210] Kennedy et al., "The Work That Visualization Conventions Do," 715–35.

[211] Saint-Martin, *Semiotics of Visual Language*, xiii.

[212] Ibid., 3.

[213] Ibid., 24.

[214] Ibid.

[215] Whysel, "Semiotics, Mapping, and Emergencies."

suggests the use of high contrast colors in motion for display in digital media. An opportunity exists to define homeland security communication further through the use of high contrast colors in motion by using features of digital systems like fading, alternating, or blinking.

(2) Shape

Altering the basic shape of a colorme contributes to the visual language by creating differentiation. Simple geometric shapes are often used to convey visual information.[216] The utilization of varying shapes is essential to communicating homeland security data, and is described by Kennedy et al. as a critical component of conveying objectivity.[217]

(3) Size

Dimension is another visual variable that helps define a colorme.[218] Varying the dimensions of colormes creates context within the visual plane, by allowing comparisons between the dimensions of adjacent colormes.[219] Size can be used to convey physical size, as well as contextual information like counts, volumes, and relative importance.

(4) Texture

Texture implies the sense of touch, but can also be conveyed visually. Conveyance of visual texture involves modulating color into regular and irregular patterns and is a powerful tool in conveying additional depth to a colorme.[220] While most closely associated with art and painted media, texture in homeland security visual communications involves varying patterns and modulations of colors within the colorme to convey critical information. This convention is best practiced on information that occupies area, as texture is difficult to convey by point. Examples of potential uses for

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[216] Kennedy et al., “The Work That Visualization Conventions Do,” 715–35.

[217] Ibid., 715.

[218] Saint-Martin, *Semiotics of Visual Language*, 55.

[219] Ibid., 54.

[220] Ibid., 50.

texture in homeland security situational awareness could include varying the texture on mapped flood areas to depict the known depth of flood waters, a capability that was notably missing from ANSI INCITS 415-2006 point symbols.

(5) Vector

Vector conveys motion within the colorme, and adds additional contextual information.[221] When a colorme is placed on a GIS, and directional vector information is included, the observer can determine both current location and direction. For homeland security visual communication, we might consider two vectors contextually relevant, actual direction and intended (anticipated) direction. Rapid visual identification of colormes with discrepancies in these two vectors would add important context for homeland security responders.

(6) Compounding

All these potential properties of a colorme can be combined in various ways to create an elegant but simple visual language that can be overlaid on maps to convey identity, location, direction, composition, and intention. Compounding colors with shape and size are useful for the creation of point symbols. Compounding contrast with texture, color, and size is useful for differentiating polygonal shapes with volume. Compounding these properties creates the metalanguage of cartographers and is ideal for network-centric homeland security response.

C. CONVEYING CONTEXT IN HOMELAND SECURITY SYMBOLOGY

Visual communication requires the addresser and addressee to convey meaning successfully through signs and symbols. While the literal interpretation of “what” can be conveyed in a symbol, true understanding comes from the conveyance of “what” in context.[222] Without context, the true meaning of a sign is much more likely to be lost in

[221] Saint-Martin, *Semiotics of Visual Language*, 61.

[222] Paul Vickers, Joe Faith, and Nick Rossiter, “Understanding Visualization: A Formal Approach Using Category Theory and Semiotics,” *IEEE Transactions of Visualization and Computer Graphics* 19, no. 6 (June 2013): 1048–61.

the conveyance. Vickers, Faith, and Rossiter state “no sign can properly be interpreted without first contextualizing it.”[223]

Simply identifying what something is, and where it is located, has some inherent value to homeland security responders. As Figure 2 depicted, these are the most basic requirements of mapped situational awareness data, but if this was the extent of the information needed to create situational awareness, then ANSI INCITS 415-2006 would not have experienced adoption issues. Responders need to know more than what and where to develop comprehensive situational awareness that leads to better decision making. When communicating visually, responders need contextual information that allows them to develop situational awareness.

Kennedy et al. listed four conventions required for the conveyance of trustworthy contextual information including two-dimensional viewpoints, clean symbol design, simple geometric shapes and lines, and the *inclusion of data sources*[224] [Emphasis added]. While not specifically expressed in their work, the inclusion of data sources should be expanded to mean the inclusion of contextual data within the symbols themselves. This contextual data should be drawn from the attributes of the feature being represented, creating situational context beyond the “what and where” of a simple point symbol. A hypothetical attribute table for a common municipal fire engine is depicted in Table 1.

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[223] Vickers, Faith, and Rossiter, “Understanding Visualization: A Formal Approach Using Category Theory and Semiotics,” 1049.

[224] Kennedy et al., “The Work That Visualization Conventions Do.” Emphasis added.

Table 1. Hypothetical Resource Attribute Table

1	FEMA Resource Type	Class 1 Fire Engine
2	Unit Identifier	Engine #6
3	Status	Assigned
4	Federal/State/Local	Local
5	Owner	City of Everett
6	Souls	3
7	Current Status	Enroute
8	Incident Assigned To	#12345
9	Incident Location	Address or coordinates
10	Radio Talkgroup	Local Channel 5
11	Operational Cycle Start	08/01/2016 08:00:00
12	Operational Cycle End	08/01/2016 17:00:00
13	Fuel Type	Diesel
	Fuel Capacity	45 Gallons
	Current Fuel Level	22 Gallons
14	Current Speed	25

While a very simplistic attribute table, a great deal of contextual information exists within it, or can be easily calculated from its data. In this example, the identity of the unit, the number of souls assigned to that unit, its current status and incident assignment and remaining fuel can be derived from the values. When combined with GPS and a GIS, this attribute table could be used to provide contextual data in conjunction with relative location of other resources within a given map extent. Certainly, an attribute table like this one could underlie the simple GIS depiction of Figure 2, and with a little user or remote sensor input that attribute table might contribute the needed context for situational awareness. However, this thesis proposes that process be automated, with elements drawn from the attribute table for rapid sharing of situational awareness. Figure 15 is a magnification of Figure 2.

Figure 15. Magnification of Figure 2

First, consider the possible cartographic pragmatics of Figure 15. Assuming that north is conventionally agreed to be the top of the display and the lines are part of an unnamed street network, a user can deduce some information about the two overlaid units. “E6” is north and west of “3133.” With some training in the system, an understanding of the labeling of units reveals “E6” to be a local fire engine and “3133” to be a local city police car. These two point symbols draw only one piece of data from a hypothetical attribute table: unit identifier.

Assuming the system depicted allows users to query for a feature attribute table similar to that in Table 1, additional contextual information could be drawn from the attribute data to answer situational awareness questions like: are these two units assigned to the same incident? What is the count of responder souls represented by these two units? Are they federal, state, or local assets? When compared to the time of day, how far into their operational cycles are they? What time will they require replacements? Assuming the feature attribute table is accessible and kept up-to-date, simple math will allow for all these calculations. However, creating symbols that compound semiotic principles would allow the computer to do the simple computations and display the situational awareness data in a much more comprehensible manner. Figure 16 is a hypothetical symbol framework utilizing contextual elements drawn from an attribute table.

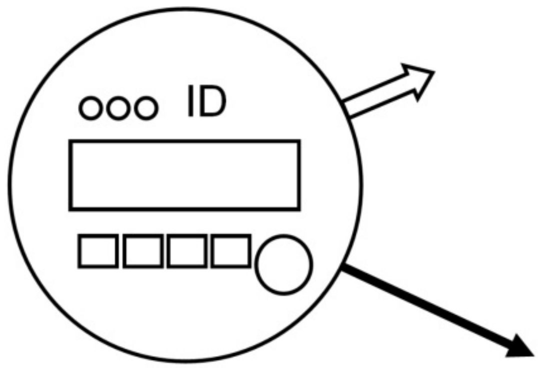
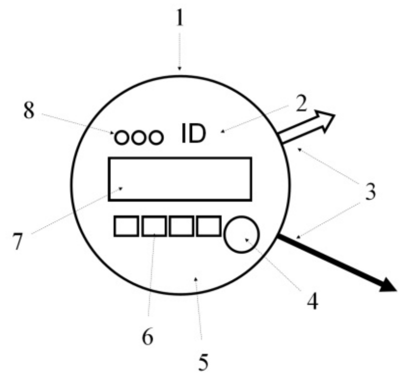


Figure 16. Proposed Hypothetical Point Symbol with Added Context

Figure 16 is a hypothetical design for conceptualizing a homeland security point symbol basic framework that incorporates data from the feature attribute table to create context. Elements of the hypothetical framework are described in Figure 17.



1	Outer frame shape
2	Feature Unit Identifier
3	Directional vectors (Actual and assigned)
4	Work cycle countdown timer
5	Frame fill area
6	Sensor bank
7	Inner frame shape
8	Unit status (available, assigned, unavailable)

Figure 17. Elements of a Proposed Hypothetical Point Symbol

Figures 16 and 17 depict a hypothetical framework for designing homeland security symbols that incorporate information from the feature's attribute table, which when added to a GIS, will provide answers not only to “where am I, and my forces” questions, but also critical contextual information about the features themselves. Semiotic principles can be further applied to this symbol to take full advantage of human perception of color, shape, size, texture, and vector. As depicted, these elements also take advantage of the principle of compounding. Figure 18 applies a few more visual elements to the hypothetical framework like color, and shape, to illustrate further the use of semiotic principles to improve the delivery of contextual data.

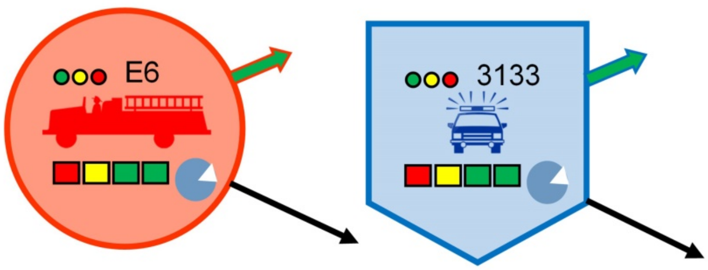


Figure 18. Point Symbols with Compounded Semiotic Principles

With these compoundable features available, the symbol can then be altered as the attribute data changes over time, allowing for real-time situational awareness. Figure 19 depicts a hypothetical symbol displaying current attributes.

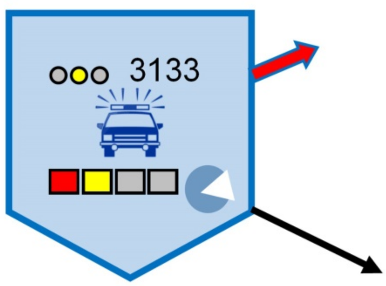


Figure 19. Point Symbol Depicting Evolving Attributes

Interpretation of this symbol requires very little training or reference to a cataloged legend. The outer frame identifies a law enforcement asset, while the inner frame further defines it as a patrol unit. The unit identifier names it patrol car "3133." The work cycle timer draws data from the attribute table to calculate the work time remaining. Cartographic pragmatics require a standard scale to be assigned to the full value of such a timer. The sensor bank could be assigned to the vehicle fuel level, in this case, showing one-half tank remaining. The unit status bar identifies this unit as being assigned to an incident, and the directional vectors depict approximate ground speed via arrow color and a discrepancy between the actual direction of travel and the assigned objective. Figure 20 is a comparison of these contextually relevant hypothetical symbols to symbols that provide no little contextual information.

Original

Context Added

Figure 20. Comparison of Point Symbols with and without Context

Applying basic principles of semiology to mapped homeland security symbols allows for the creation of a metalanguage for situational awareness. Both Figure 20 images answer the basic situational awareness questions about relative resource locations described by Dunn.[225] The hypothetical symbols, with information derived from their attribute tables, go further and provide desired information found to be lacking by responders using ANSI INCITS 415 symbols sets.[226] When combined with the power of a wireless network, a situational awareness metalanguage is shared across an entire user group without the restrictions of simplex or duplex voice communications.

Robinson, McEachren, and Roth found responders desire full-color symbols able to display the hierarchical nature of homeland security response, which was a described weakness of ANSI INCITS 415.[227] In the example, the outer frame of the hypothetical model can be used to differentiate between the various response disciplines while the inner frame can be used to depict the placement of that resource within its disciplinary hierarchy. Another barrier mentioned by Robinson was the inability to adapt symbols to specific responder missions and physical infrastructure. The hypothetical model can be adapted with ease to represent various asset types, as well as building elements. Figure 21 symbolizes a stairwell and provides contextually relevant information found in the attribute table of the feature.

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[225] Dunn, *Blue Force Tracking—The Afghanistan and Iraq Experience and Its Implications for the U.S. Army*.

[226] Robinson, MacEachren, and Roth, "Challenges for Map Symbol Standardization in Crisis Management."

[227] Ibid.

Figure 21. Stairwell Symbol, Everett Fire Department, Everett WA[228]

Figure 21 compounds semiotic principles and is one of several "building features" depicted in the Everett Fire Department *GIS Symbols Key and Users Guide*. Without national guidance, the Everett Fire Department distinguished all building features as being yellow on a black background, in a square or rectangular shape.[229] Figure 21 graphically identifies stairwell #5 using a high-contrast symbol and is labeled with the floors the stairwell services, in this case, floors 1 through 2. Additional modifiers for stairwells at the Everett Fire Department include denoting the presence of fire suppression standpipes and roof access.[230] Providing firefighters with these critical contextual data points allows them to make better decisions than would be possible with a simple point symbol depicting the location of a stairwell.

D. HOMELAND SECURITY CARTOGRAPHIC CONVENTIONS

Visual communication between parties and across networks requires a common understanding of the language fundamentals and a medium upon which to converse. The U.S. Army defines the elements of its visual language in a reference guide to their symbology. ADRP 1-02, the legend of the U.S. Army Terms and Military Symbols clearly defines each possible language item and its possible semiotic variations.[231] While

[228] Source: David De Marco, *Fire Services Preplanning GIS Symbols Key and Users Guide* (Everett, WA Fire Department, 2016).

[229] Ibid., 2.

[230] Ibid., 7.

[231] United States Army, *ADRP 1-02 Terms and Military Symbols*.

ANSI INCITS 415-2006 attempts to create a similarly constructed legend for homeland security visual communications, it has been found to be lacking.[232] No national standard defines the environment in which these symbols might be used, resulting in a wide range of unique communication tools that are not necessarily interoperable.

Basic mapping conventions are referred to as "cartographic pragmatics."[233] Cartographic pragmatics define the map that becomes the canvas for visual communication of situational awareness data; without a common set of mapping pragmatics, visual communication of data will be inconsistent, varying from one map tool to another. Cartographic conventions for items like north orientation, visual decay rate, and scales for changes in levels of detail are essential to creating a common visual language for symbolized situational awareness data.[234]

An important cartographic pragmatic that must be applied to homeland security is known as "scale dependent rendering."[235] In short, the scale of a GIS map area being viewed, when compared to the size of the screen viewing it, will help determine the features to be displayed. As users draw in closer to mapped information, their ability to view increasing resource resolution allows for more and more contextual information. Currently, no national standard exists for symbolizing situational awareness information with varying degrees of resolution based on map scale. Figure 22 uses the elements of the hypothetical symbol framework to alter their appearance at different map scales, delivering increasing contextual information with decreasing map scales.

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[232] Robinson, MacEachren, and Roth, "Challenges for Map Symbol Standardization in Crisis Management."

[233] Whysel, "Semiotics, Mapping, and Emergencies."

[234] Longley et al., *Geographic Information Systems and Science*.

[235] "ArcGIS Desktop Help 9.2—Scale-Dependent Rendering in ArcGlobe," last modified February 29, 2008, http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Scale-dependent_rendering_in_ArcGlobe.

Figure 22. Scale Dependent Rendering

Full-color variations of the inner and outer frames allow for manipulation of map scope without creating an overload of indiscernible data when looking at wide areas. As the view of the homeland security map decreases past defined scale measures, the display of asset contextual information increases. In general, as the resolution (or scale) of a map view becomes more and more granular, additional semiotic elements should be compounded for improved communication. In Figure 22, the same feature is exhibited with progressively increasing semiotic features as resolution improves. Modifications to color, shape, size, texture, and vector allow for seamless transitions from one scale to another. This is an essential cartographic pragmatic that must be consistent across national map platforms to ensure communications interoperability and must be defined in any national homeland security situational awareness semiotic language.

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VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

The situational awareness needs of American homeland security responders are strikingly similar to the needs of American warfighters. Friction, as defined by the U.S. Marines, is also present in homeland security response and creates confusion among responders very similar to the "fog of war."[236] Warfighters and responders also face uncertainty, fluidity, and disorder in their respective endeavors. Similarities largely end there, as the armed forces are better organized and better funded than homeland security responders. When comparing only four branches of armed services funded exclusively from the federal budget, the Army, Navy, Air Force, and Marines have an advantage over homeland security responders with separate budgets and operations from 18,000 police agencies, 27,000 fire agencies, and 9,500 emergency medical services agencies. American armed forces have developed doctrine and tools for managing these ever-present battlefield issues with greater success than their homeland security counterparts and must be looked to for guidance by homeland security responders.

Warfighters have identified the wireless digital information network as the key to managing that fog of war created by friction, uncertainty, fluidity, and disorder.[237] Successful warfighting is increasingly dependent on the presence of a network, leading military leaders to describe their work as network-centric, and identifying the development of network-centric warfare as their top modernization priority.[238] The presence of a network in the battlespace provides four key advantages to the warfighter and is desirable for homeland security responders:

- A robustly networked force improves information sharing.

[236] U.S. Marine Corps Staff, *Warfighting*, 3.

[237] U.S. Department of Defense, "Network Centric Warfare Department of Defense Report to Congress."

[238] Erwin, "U.S. Troops Loaded with Technology, But Can't Harness the Power of the Network–Blog."

- Information sharing and collaboration enhance the quality of information and shared situational awareness.
- Shared situational awareness enables self-synchronization.
- These, in turn, dramatically increase mission effectiveness.[239]

These tenets of network-centric warfare are desirable for homeland security response, which is driving the development of network-centric response infrastructure.

Congress has recognized the value of these tenets in homeland security and authorized the creation of a national broadband network dedicated to achieving them in the homeland.[240] FirstNet will provide the backbone for nationally networked homeland security communications and information exchange.[241] With no national guidance, network-centric response tools are developing sporadically and incongruously among the myriad public and private enterprises servicing homeland security response, leaving the national interoperability issue unresolved.

A map lies at the heart of situational awareness, and a geographic information system lies at the heart of tools developed for situational awareness among warfighters. Homeland security situational awareness tools in development mirror the efforts already well underway within the military. Network-centric communication via GIS allows for visual communication between networked responders. Symbolic visual communication is a metalanguage, able to convey situational awareness information more accurately and effectively than verbal communication.[242] To overcome the interoperability issues that have plagued homeland security responders time and time again, a common national visual language for use in map-based network-centric response must be developed and effectively implemented.

To be effective as a metalanguage, homeland security symbols must communicate more than the "what and where" of mapped resources; they must also supply contextual

[239] U.S. Department of Defense, "Network Centric Warfare Department of Defense Report to Congress."

[240] *Middle Class Tax Relief and Job Creation Act of 2012*, Pub. L. No. 112-96 (February 22, 2012).

[241] First Responder Network Authority, *Public Safety Advisory Committee Fact Sheet*.

[242] Saint-Martin, *Semiotics of Visual Language*, xiii.

information useful to responders. By compounding basic principles of semiotics and drawing data from the attributes of the mapped homeland security features, homeland security symbols sets can communicate contextual information critical to situational awareness. The following recommendations are intended to guide policymakers in their efforts to achieve that purpose.

B. RECOMMENDATIONS

The combination of these recommendations will result in the development of an interoperable visual language for communication of situational awareness among homeland security responders.

1. Recommendation #1: Identify the Tenets of Network-centric Response as Essential to the Homeland Security Enterprise

The four tenets of network-centric warfare reported to Congress by the DOD apply verbatim to homeland security response. Therefore, the DHS should recognize a network-centric response as doctrine, and direct the development of responder situational awareness tools for use in that environment. Critically, wireless networks allow for the use of visual communication, a metalanguage, which when combined with the multiplexing capabilities of computers, creates exponential growth in contextually rich situational awareness data exchange among responders. Network-centric response brings General McChrystals battlefield benefits to the homeland:[243]

- Networks decentralize decision making, creating speedier reactions to changing conditions
- Networks remove institutional boundaries, allowing cooperation
- Networks allow more efficient utilization of resources
- Networks facilitate competence in decision-making, at all levels of rank

The presence of a network is essential to homeland security, but realizing these benefits will require the development of a common language for use in a networked environment.

[243] McChrystal, “It Takes a Network.”

2. Recommendation #2: The DHS Must Identify a GIS as the Medium within Which Networked Visual Communication of Situational Awareness Will Occur

Human map making dates to earliest recorded history, and although ancient in concept, a map still lies at the heart of situational awareness for American warfighters and American homeland security responders.[244] If a wireless network is a backbone for communicating situational awareness, a geographic information system should be recognized as the workspace in which that visual communication of situational awareness develops. The ability of a GIS to geolocate tabular data is unsurpassed in communicating the information needed to develop situational awareness. A GIS is a whiteboard upon which a visual metalanguage is shared across a networked force of responders.

3. Recommendation #3: Define a Common Set of Cartographic Pragmatics and Cognitive Compromises Specific to Homeland Security

Cartographic pragmatics and cognitive compromises are the conventions that define the rules of the mapping workspace.[245] The DHS must define a basic set of each for use in a network-centric response environment. Defining a standard north orientation and minimum base layers for use in situational awareness mapping will allow diverse responders to access and understand the communication medium in a highly interoperable manner.

Scale-dependent rendering and layering data within a GIS is critical to managing information overload among decision makers.[246] By altering the volume of contextual information displayed based on the scope and scale of a displayed GIS, decision makers are able to continue making informed decisions relative to the scope and scale of their responsibilities. Varying magnifications allows the decision makers to drill into local data or view global data, depending on their need. The DHS must define conventions for

[244] "Successful Response Starts with a Map: Improving Geospatial Support for Disaster Management."

[245] Whysel, "Semiotics, Mapping, and Emergencies."

[246] Hudson and Rzasa, "Knowledge Visualizations: A Tool to Achieve Optimized Operational Decision Making and Data Integration."

scale-dependent rendering so it is consistent nationally. This thesis suggests four separate point symbols for depicting the same resource at different scales. National policy should define the scopes and scales at which these symbols vary.

4. Recommendation #4: Symbolize the FEMA's Resource Guidebook to Create an Initial National Homeland Security Point Symbols Set

A GIS has the inherent ability to sort and display features based on tabular data contained in a feature attribute table. This sorting is typically achieved visually by grouping features and displaying them in layers.[247] An essential part of developing a visual communication language for homeland security will be to create groupings that will allow mapped features to be sorted into logical layers. While a myriad homeland security-related features can and should be included in a visual language for situational awareness, the FEMA resource definitions guide has already cataloged an essential feature set.[248] Conveniently, FEMA has already subdivided the resources commonly used and exchanged during homeland security incidents into eight general categories:[249]

- Animal health resources
- Emergency management resources
- Emergency medical services resources
- Fire/HazMat resources
- Health and medical resources
- Law enforcement resources
- Public works resources
- Search and rescue resources

These groupings represent the eight general layers into which homeland security resources should be divided for visual communication. The basic symbol framework depicted in Figure 16 suggests an outer frame, each of which should be designed to

[247] Longley et al., *Geographic Information Systems and Science*.

[248] Federal Emergency Management Agency, *Resource Definitions 120 Resources* (Washington, DC: U.S. Department of Homeland Security, 2004), https://www.hsdl.org/?view&did=450515.

[249] Ibid., ii.

differentiate between these eight groupings. The inner frame can then be used to identify the specific feature contained within each grouping and their relative position within each grouping's hierarchy of resources.

5. Recommendation #5: Design Attribute Tables for All Homeland Security Resources

The visual language used to convey situational awareness among homeland security responders must convey more than "what and where." The failure of the existing ANSI point symbols set for homeland security is a result of their inability to convey contextual information, and in a GIS, contextual information is stored in a feature attribute table. The FEMA Resource Guide does not define the critical attributes of the various typed resources. The DHS must organize an effort to develop attribute tables for each resource it types. A few attribute fields will be common to all typed resources but many are unique within each grouping and even more within each individual resource. SMEs from each of the eight fields must be consulted to identify the attributes of their various features to ensure a complete attribute table is designed for each and every cataloged FEMA resource.

An identified, standardized attribute tables will allow software engineers to build the applications able to make use of each field, with emphasis on critical attributes. With a standardized attribute table, manufacturers can make use of increasingly affordable sensor arrays to begin automating the process of reporting some attribute fields like fuel level, temperature, speed, or geolocation. This table will underlie the point symbols used for visual communication and be the source of contextual data for the symbols themselves. Without an attribute table for each resource, it will be impossible to create a contextually rich visual language.

6. Recommendation #6: Define Modifiers for the National Symbols Set Drawn from the Attribute Tables of Resources to Create Useful Context within Each Symbol

The DHS should collaborate with the ANSI to redevelop the national point symbols set for homeland security mapping. The new symbols set should be designed to eliminate the shortcomings of ANSI INCITS 415-2006 by taking full advantage of basic semiotic principles in their design and create context by incorporating feature attribute data within the symbol itself. Size, shape, and color of the symbol outer frame should be used to differentiate visually between the eight resource type layers. The inner frame should apply these same semiotic principles to visually differentiate further between the resource types within each layer.

Additionally, each FEMA-typed feature should have four symbols developed for use in scale-dependent rendering, with the volume of contextual information increased with each symbol as the scope and scale of the map decreases. Each symbol must display some information from its attribute table to create much-needed context. Frame amplifiers similar to those in use by the U.S. Army (see Figure 14) should be defined for the display of contextually relevant attribute data within the symbols themselves.

C. AREAS OF FUTURE RESEARCH

(1) Expand the National Symbols Set to Include Polygonal Shapes

While it is outside the scope of this thesis, there is a need for national standards for symbolizing homeland security features that cannot be depicted by a single point. Polygonal areas of flooding, wildfires, crime scenes, or homeland security bounded areas of any kind deserve the same design consideration as point symbols. Texture is a semiotic principle not well addressed by this thesis, as it is difficult to convey via a single point symbol; however, in addition to the size, shape, and color variations found in point symbols, those features requiring polygonal volume should find great benefit from varying textures.

(2) DARPA Squad X Implications

As an open-source thesis written by a civilian, it is impossible to know the true state of the art of situational awareness technology within the armed forces. Driesslein offers a non-classified glimpse into the evolving landscape of networked awareness in the armed forces with his response to the DARPA Squad X competition.[250] It is clear the

[250] Driesslein, "Scalable Mobile Ad Hoc Network (MANET) to Enhance Situational Awareness in Distributed Small Unit Operations."

armed forces are well along in their research and development of low-cost, lightweight, man-portable hardware and sensor arrays that will carry network-centric warfare benefits out of mounted units to the individual soldiers.

This thesis recommends a visual language for communication of situational awareness between mounted and fixed homeland security assets. The Squad X competition results demonstrate that networked information and decision making will eventually arrive at the single soldier resolution; thus, it can be inferred that while it may occur in the footsteps of the armed forces, it will also eventually arrive at the single responder resolution for homeland security. This suggests that any development of a national symbol set for homeland security situational awareness should leave an allowance for future increases in granularity. Every effort should be made to follow the example being set by the armed forces in this area.

(3) Create a National Infrastructure Symbols Set Which Conveys Context

Also outside the scope of this thesis, but relevant and necessary for responders, is the ability to map essential features of their community infrastructure. Features of building construction, known community hazards, drug houses, hazardous storage, and many others also need to be mapped and symbolized nationally. Figure 21 showed an example of adding contextual information to a building feature symbol. The principles of semiotics and context should be applied to the expansion of the homeland security symbols set to include these kinds of features to improve further response effectiveness and efficiency.

(4) High-Resolution Z-Axis Geolocation and Augmented Reality

Global positioning and GIS mapping have historically converted three-dimensional data to two-dimensional data by rasterizing and layering it.[251] Both these systems depend on accurate *x* and *y-axis* information to carry out the geolocation process, but even these systems are evolving rapidly to include a third dimension. Three-

[251] Longley et al., *Geographic Information Systems and Science*.

dimensional mapping is becoming increasingly common and research is being directed at methods to develop high-resolution *z-axis* data for mapped features.[252]

Highly reliable *z-axis* geolocation will open a new era in mapped situational awareness by providing accurate indoor altitude data, creating a use for interior mapping of floorplans at all elevations. While this technology is not currently available, it lies at the top of the priority list for both military and civilian researchers.[253] Accurate x, y, and z-axis location data, when combined with developing visual augmentation technology, may be combined with man-portable networked technology to provide an augmented reality view, even in low or no visibility environments. Thus, the trustworthy two-dimensional symbols suggested in this thesis must eventually become three-dimensional symbols, adding another important semiotic element for compounding meaning. It is essential the DHS begin the national process of familiarizing responders with network-centric response, visual communications, and mapped situational awareness as the technology continues to advance.

[252] Felts et al., *Public Safety Communications Research (PSCR) Program Location-Based Services R [and] D Roadmap.*

[253] Ibid.

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